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From Data to Decision: An Implementation Model for the Use of Evidence-based Medicine, Data Analytics, and Education in Transfusion Medicine Practice

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FROM DATA TO DECISION: AN IMPLEMENTATION MODEL FOR THE USE OF
EVIDENCE-BASED MEDICINE, DATA ANALYTICS, AND EDUCATION IN
TRANSFUSION MEDICINE PRACTICE

by

Nazanin Tabesh

A Dissertation Submitted in
Partial Fulfillment of the
Requirements for the Degree of

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ABSTRACT

FROM DATA TO DECISION: AN IMPLEMENTATION MODEL FOR THE USE OF EVIDENCE-BASED MEDICINE, DATA ANALYTICS, AND EDUCATION IN TRANSFUSION MEDICINE PRACTICE

by

Nazanin Tabesh

The University of Wisconsin-Milwaukee, 2015
Under the Supervision of Professor Timothy B. Patrick

Healthcare in the United States is underperforming despite record increases in spending. The causes are as myriad and complex as the suggested solutions. It is increasingly important to carefully assess the appropriateness and cost-effectiveness of treatments especially the most resource-consuming clinical interventions. Healthcare reimbursement models are evolving from fee-for-service to outcome-based payment. The Patient Protection and Affordable Care Act has added new incentives to address some of the cost, quality, and access issues related to healthcare, making the use of healthcare data and evidence-based decision-making essential strategies. However, despite the great promise of these strategies, the transition to data-driven, evidence-based medical practice is complex and faces many challenges.

This study aims to bridge the gaps that exist between data, knowledge, and practice in a healthcare setting through the use of a comprehensive framework to address the administrative, cultural, clinical, and technical issues that make the implementation and sustainability of an evidence-based program and utilization of healthcare data so challenging. The study focuses on

promoting evidence-based medical practice by leveraging a performance management system, targeted education, and data analytics to improve outcomes and control costs.

The framework was implemented and validated in transfusion medicine practice. Transfusion is one of the top ten coded hospital procedures in the United States. Unfortunately, the costs of transfusion are underestimated and the benefits to patients are overestimated. The particular aim of this study was to reduce practice inconsistencies in red blood cell transfusion among hospitalists in a large urban hospital using evidence-based guidelines, a performance management system, recurrent reporting of practice-specific information, focused education, and data analytics in a continuous feedback mechanism to drive appropriate decision-making prior to the decision to transfuse and prior to issuing the blood component.

The research in this dissertation provides the foundation for implementation of an integrated framework that proved to be effective in encouraging evidence-based best practices among hospitalists to improve quality and lower costs of care. What follows is a discussion of the essential components of the framework, the results that were achieved and observations relative to next steps a learning healthcare organization would consider.

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This work is dedicated to my parents. All I have and will accomplish is only possible due to their love and sacrifices. Also to my grandmother and my brother whose love, endless support, and encouragement sustained me throughout.

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LIST OF ABBREVIATIONS

AABB	American Association of Blood Bank
ABO	Blood Group System
ACA	Affordable Care Act
ACO	Accountable Care Organizations
AHA	American Hospital Association
AHRQ	Agency for Healthcare and Quality
AMA	American Medical Association
CDSS	Clinical Decision Support System
CMS	Center for Medicare Services
CMV	Cytomegalovirus
CPOE	Computerized Physician Order Entry
EBM	Evidence-Based Medicine
EBP	Evidence-Based Practice
EHR	Electronic Health Record
EHR	Electronic Medical Record
FDA	Food and Drug Administration
FNHTR	Febrile Non Haemolytic Transfusion Reactions
GDP	Gross Domestic Products
H.CUP	Healthcare Cost and Utilization Project
HHS	United States Department Of Health And Human Services
HIE	Health Information Exchanges
HIMMS	Healthcare Information and Management Systems Society

HIT	Health Information Technology
HITECH	Health Information Technology for Economic And Clinical Health Act
HIV	Human Immunodeficiency Virus
HLA	Human Leukocyte Antigen
HTLV I/II	Lymphotropic Virus
ICD	International Classification of Disease
ICU	Intensive Care Unit
IT	Information Technology
JC	The Joint Commission
KPI	Key Performance Indicator
MeSH	Medical Subject Heading
MPPS	Medicare Prospective Payment System
NLM	National Library of Medicine
OECD	Organization of Economic Cooperation and Development
PBM	Patient Blood Management
PMS	Performance Management System
PPACA	Patient Protection and Affordable Care Act
RBC	Red Blood Cells
TACO	Transfusion Associated Circulatory Overload
TA-GVHD	Transfusion Associated Graft Versus Host Disease
TRALI	Transfusion Related Acute Lung Injury
TRICC	Transfusion Requirements in Critical Care
WHO	World Health Organization

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Chapter 1: Problem Statement

1.1 Introduction

Healthcare in the United States (U.S.) is underperforming despite record increases in spending. The causes are as myriad and complex as the suggested solutions. It is increasingly important to carefully assess the appropriateness and cost-effectiveness of treatments including the most resource-consuming clinical interventions ^{1,2}. One of the most promising solutions lies in a shift from authority-based medicine to evidence-based medicine (EBM). While there have been signs of a shift in this direction ^{3,4}, very few healthcare organizations can point to tangible examples of improved outcomes and cost reduction that are directly the result of more informed decision making. The Patient Protection and Affordable Care Act, commonly referred to as the Affordable Care Act (ACA) has added new incentives to address some of the cost, quality, and access issues related to healthcare, making evidence-based decision-making an increasingly important strategy.

Despite its great promise, the transition to evidence-based medical practice faces many challenges. It is commonly known that healthcare organizations are “data rich and information poor” ⁵. This study demonstrates the effectiveness of a framework that bridges the gaps that exist between data, knowledge, and practice through the use of evidence-based guidelines, data analytics, enhanced contextualized data-driven practice information, education focused on the latest evidence, and feedback mechanism to assess the changes in practice. The American Hospital Association (AHA) has made a series of recommendations at this transformational

junction in healthcare delivery. The AHA four priority strategies are incorporated into this study's process framework and include: alignment of hospitals, physicians and other healthcare providers across the care continuum; utilization of evidence-based practices to improve quality and patient safety; improvement of efficiency through productivity and financial management, and development of integrated information systems in a cohesive manner to operationalize the multiple components.

Even though the basic principles behind evidence-based medicine (EBM) have been known for many years, the concept and the approach to integrating evidence-based decision making into day-to-day practice has only begun to evolve in the past twenty years ⁶. Different approaches to the development and implementation of evidence-based practice have been proposed and used, including: professional education and development, audit and feedback, evidence-based guidelines, total quality management, economic incentives, and organizational changes. A number of well-designed studies ⁷⁻¹¹ have examined attempts to modify clinical practices using mostly one or infrequently more than one of the above approaches ⁷. However, an understanding of just which approaches are most effective in which settings remains unclear.

Blood transfusion has been the focus of practice improvement efforts because it is among the top ten coded hospital procedures ^{12,13} with significant cost and patient outcome implications. Patient Blood Management (PBM) is defined as “an evidence-based, multidisciplinary approach to optimize the care of patients who might need transfusion” ¹⁴. Research findings in the areas of clinical evaluation of patients, transfusion outcomes, and decision-making processes have shown compelling evidence for the need for improvement of transfusion medicine practice. Blood is a

precious and a limited resource that carries inherent risks for patients when transfused ¹⁵. Extensive donor screening and infectious testing have made blood products much safer by drastically decreasing the rate of transfusion-transmitted infectious diseases. However, recent discoveries point to increased non-infectious transfusion hazards that have emerged as the leading complication of transfusion-associated morbidities ^{16,17} and even mortalities ¹⁸⁻²⁰. Transfusion of allogeneic blood has long been suspected of consuming “more healthcare resources than previously reported”²¹. The underestimated cost and overestimated effectiveness of this long-standing and common clinical practice¹ have contributed to higher associated expenditures which strain healthcare organization budgets.

Lack of evidence for the need for practice improvement is not the issue. “Transfusion medicine is currently adapting the principles and research methodologies that support EBM” ²². High level research has been undertaken at the same rate as in all other medical specialties in terms of numbers of randomized controlled trials and meta-analyses²². However, even today broad variation exists in transfusion medicine practice within and across hospitals and healthcare organizations. There is a demonstrated need to bring PBM evidence into the day-to-day practice of physicians and other healthcare providers. There are compelling motives and numerous incentives to introduce EBM practices into transfusion medicine as part of a PBM program.

In this study, a comprehensive framework was developed and used to implement a data-driven, evidence-based patient blood management program at a large (385 bed), accredited, general medical hospital served by BloodCenter of Wisconsin in Milwaukee. The study demonstrates an approach that bridged the gaps that exist between data, knowledge, and practice through the use

of evidence-based guidelines, enhanced contextualized data-driven reports and focused education on the latest evidence. An analytics framework provided a feedback mechanism to evaluate changes directly impacted by the program, identified new areas for improvement, and helped avoid unintended consequences and outcomes. Focus on the tight integration of these elements successfully altered healthcare providers' inappropriate practices, increased adherence to the medical practices based on best scientific evidence (EBM), led to appropriate decision-making and interventions (EBP), and resulted in cost savings. The method, applicable in areas of healthcare beyond transfusion medicine, improved patient outcomes and reduced healthcare expenditures.

1.2 Current Healthcare Landscape

1.2.1. United States Healthcare System

In 2011, total healthcare spending accounted for 10.1 percent of the world's gross domestic product (GDP) ^{23,24}. At the same time, the United States spent 17.7 percent of its GDP on healthcare. This share roughly doubled from nine percent in 1980s ²⁵. Health data released by the Organization for Economic Cooperation and Development (OECD) indicate that the United States compared to any other OECD country spends more on healthcare per capita ²⁴. If healthcare expenditures continue to rise at historical rates, the Council of Economic Advisers projects the share to reach 34 percent of GDP by 2040 ²⁶. Despite the increase in healthcare spending, comparative analysis has shown that the United States underperforms in most dimensions of a high performance healthcare system (i.e. quality, access, efficiency, equity, and healthy lives) relative to other countries, such as Australia, Canada, Germany, the Netherlands, New Zealand, and the United Kingdom ²⁷.

1.2.2. United States Healthcare Complexities

The healthcare system in the U.S. is comprised of a vast array of complex interrelationships among patients, providers, payers, and insurers ²⁸, in addition to the pharmaceutical and biomedical technology industries. These interdependencies have created a multifaceted and complex care delivery model, which has been sustained for many decades by a set of mutually reinforcing elements. Some of the elements include: “organization by specialty with independent private-practice physicians; measurement of “quality” defined as process compliance; cost accounting driven not by costs but by charges; fee-for-service payments by specialty with rampant cross-subsidies; delivery systems with duplicative service lines and little integration; fragmentation of patient populations such that most providers do not have critical masses of patients with a given medical condition; siloed IT systems around medical specialties; and others”²⁹. The interlocking structure of the current healthcare system contributes to process inefficiencies, structural barriers, and system failures, which are significant impediments to quality care and prevent the delivery of effective, efficient, evidence-based health care ^{29,30}. These factors highlight the complexity and explain resistance to change.

1.2.3. Affordable Care Act

The Affordable Care Act (ACA) was signed into law on March 23, 2010. It consisted of ten separate legislative Titles with several major aims. Passing ACA introduced a significant regulatory overhaul to the current healthcare system through mandates, subsidies, and health insurance exchanges ³¹. The provisions of ACA were designed to control increasing healthcare

costs, expand coverage, and improve patient access, healthcare delivery, patient outcomes, and population health ³². The enactment of ACA drastically shifted the operational landscape of healthcare organizations, insurers, payers, patients, and care providers, by moving away from a supply driven healthcare system organized around providers to a patient-centered system, focusing on patients' needs ^{29,33}. The intent of the law was to lower overall healthcare costs by better aligning patient care with holistic approaches to treatment, with a significant focus on preventative medicine ³³ and population health. One of the major aims of ACA was to “improve health-care value, quality, and efficiency while reducing wasteful spending and making the health-care system more accountable to a diverse patient population” ³⁴. Value may be defined as “health outcomes achieved that matter to patients relative to the cost of achieving those outcomes”²⁹. Value for healthcare organizations senior executives, providers, and stakeholders translates into improving one or more outcomes without increasing cost (in some cases even lowering cost) without compromising outcomes ²⁹. Improving value is critical in the new healthcare environment. Failure to improve value can decrease profitability and competitiveness of healthcare organizations and hospitals in the marketplace. To be better positioned for the road ahead, a fundamental departure from past practices is essential.

1.2.4. Additional Healthcare Challenges

Change is inevitable for healthcare systems and hospitals in order to drive transformation, operationalize care delivery, and move from volume to value as required by ACA. Healthcare organizations and hospitals are facing mounting pressure as they deal with: increasing cost of patient care, uncertainty surrounding healthcare reform, governmental mandates, cost

containment requirements, industry consolidation, challenges in enhancing patient outcome quality and safety, population health management, change in physician reimbursement models, physician hospital relations, caring for uninsured, improving patient satisfaction, conforming to new information technology, and creating accountable care organizations³⁵⁻³⁷. Healthcare systems and care providers must operate under new sets of outcome based demands and avail themselves of the latest research evidence and technological advancements. A paradigm shift is required of healthcare systems and care providers if they are to deliver quality patient care in the most effective and efficient manner, with outcome quality tracked, rewards granted based on evidence-based best-practice and quality metrics met as measured through an aggregation of hard data³⁸.

At the industry level, the current culture of healthcare environment is characterized by “competition, misaligned incentives, and inherent distrust among stakeholders”, which is exacerbated by tensions among “consumers who ask for high service and low out-of-pocket costs, payers who select risk and limit cost, and purchasers demand more value at the lowest cost”³⁰. In addition, vast investments in biomedical research and technology, pharmaceutical, genetics and genomics research and discoveries have led to new and improved clinical approaches. Technological and scientific breakthroughs have led to a marked proliferation of new diagnostic and treatment technologies, which has led to a sharp increase in healthcare costs³⁰.

Healthcare organizations in the United States have not fully leveraged clinical data to improve health outcomes. Siloed and diverse information technology systems within and across

healthcare organizations make cost and outcome measurement difficult and limit the value of these technologies. Three major impediments to the full use of health data include: limited integration capabilities in the design of various health information systems for health information technology (HIT) and other technologies (i.e. imaging systems, lab, pharmacy, transfusion service information systems and etc.); limited access to data, which is exacerbated by inadequate adoption of electronic health records (EHRs); and lack of data standards. These barriers and more have resulted in misuse or overuse of various systems and have hampered their ability to improve quality of care and delivery of services. The “crush of information, plethora of new technologies, increased regulatory oversight, an aging population, and heightened consumer awareness and expectations have all contributed to the disorganization, fragmentation, and discontinuity of patient care”³⁰.

1.2.5. American Hospital Association Recommendations

To help healthcare systems and hospitals’ senior leadership navigate the fluid environment, the American Hospital Association (AHA) Committee on Performance Improvement has identified priority strategies and core organizational competencies to be considered by healthcare systems and hospitals in order to remain successful during this transformational period ³⁹. Among the following AHA strategies, the first four are considered major priorities:

- Aligning hospitals, physicians and other providers across the care continuum
- Utilizing evidence-based practices to improve quality and patient safety
- Improving efficiency through productivity and financial management
- Developing integrated information systems

- Joining and growing integrated provider networks and care systems
- Educating and engaging employees and physicians to create leaders
- Strengthening finances to facilitate reinvestment and innovation
- Partnering with payers
- Advancing through scenario-based strategic, financial and operational planning
- Seeking population health improvement through pursuit of the “triple aim”³⁹

The AHA recommendations highlight the need for today’s healthcare systems and care providers to operate under a new set of outcome based demands. The paradigm shift requires healthcare systems and care providers to deliver quality patient care in the most effective and efficient manner, with quality of outcomes is tracked and rewarded based on evidence-based best practice measures, and meeting various quality metrics that can be measured through aggregation and analysis of hard data³⁸.

1.2.6. Affordable Care Act Implementation Challenges

The manner in which many healthcare systems have been implementing the different components of the new healthcare law has resulted in a succession of narrow piecemeal solutions some of which are designed to preserve existing roles²⁹. Some attempts to improve consumer access to care further fragment care delivery and add to the problem. Convenient care clinics improve access to primary care, but they are not designed to provide holistic and continuous care for healthy patients, or acute and preventative care for patients with complex chronic, or acute conditions²⁹. Global capitation can strongly incentivize providers to reduce spending, without necessarily improving value or outcome for patients. Care coordination on top of a fragmented

healthcare system can produce very limited savings²⁹. Information technology solutions are a critical component of an effective patient-centered healthcare system. However, misuse, and overuse of disparate, incompatible, and heterogeneous health information systems have intensified and further fostered siloed and fragmented care delivery models despite attempts to establish care-coordination and continuity of patient care.

Practicing evidence-based medicine, for the purpose of improving quality and patient safety is appropriate but it is not without implementation challenges. Even though studies have shown that development and implementation of evidence-based clinical practice guidelines appear to be one of the most promising and effective tools for improving quality of care, many guideline are not used soon after dissemination⁴⁰. Evidence-based clinical practice guidelines become outdated quickly due to rapid advances in medical knowledge, clinical research, and technology. Quality measures and metrics are high-level and limited. Many measures track and report only providers' compliance with certain guidelines, and dismiss outcomes achieved related to adherence with the guidelines. Measuring compliance with guidelines does not translate into practicing evidence-based medicine, especially if improved patient outcomes are unquantifiable. Disappointing results from various attempted cost reduction strategies has fostered skepticism about whether value improvement in healthcare is possible with some concluding that the only solution to escalating cost of healthcare is rationing of services and shifting the cost to patients or taxpayers

²⁹ .

1.3. Reshaping the Healthcare Ecosystem

The healthcare ecosystem is being reshaped by two powerful and opposing economic forces: (1) to improve quality of care, and (2) to reduce cost. There is pressure to do more with less. In order to achieve more with less, any healthcare organization with a vision of the future must face a fundamental question, how to best to use limited resources while better managing patient care? The answer to this question lies within healthcare organizations' data. Clinical, administrative, and other healthcare related data holds the key to transforming the healthcare system, by providing greater insight to patients, providers, and policy makers on the appropriate interventions, quality, and cost of care ⁴¹. As a result, the healthcare system model is changing into “information driven”, “evidence-based”, and “outcome-driven” model ⁴². Using technology effectively and managing the overwhelming quantity of data to derive new information are at the forefront of the change.

1.3.1. Information Driven Healthcare

Healthcare data offer the opportunity to accelerate progress on the six characteristics of quality care, in which a healthcare system must deliver. These characteristics include:

1. Safe: Care should be as safe for patients in healthcare facilities as in their homes;
2. Effective: Science and evidence behind healthcare should be applied and serve as the standard in the delivery of care;
3. Efficient: Care and service should be cost effective and waste should be removed from the system;
4. Timely: Patients should experience no waits or delays in receiving care and services;

5. Patient Centered: The system of care should revolve around the patient, respect patient preferences, and put the patient in control;
6. Equitable: Unequal treatment should be a fact of the past; disparities in care should be eradicated ⁴³⁻⁴⁵.

Addressing the above dimensions of quality care, necessitate an understanding of the scope of the potential and missed opportunity. This requires a sound knowledge of existing healthcare data (i.e. disparate data sources, types, accessibility, and use) ⁴¹. The combination of administrative and clinical data is a powerful and vital resource. Significant quantities of data permeate healthcare organizations and have the potential to transform healthcare delivery and performance ^{46,47}. However, data alone is neither information nor knowledge. Data requires collection and processing (manipulation of items of data) to produce information ^{47,48}. The combination of a robust information technology infrastructure, technology expertise and informatics expertise are required to perform the data profiling, aggregation, analytics, visualization, interpretation, and presentation in order to produce meaningful information and provide the knowledge that is required to contribute to informed decision-making in healthcare services and policies ⁴⁷. However to date, many healthcare organizations have not fully embraced the expertise, technologies, and key business management processes or techniques (such as knowledge management, data mining, business intelligence, analytics, intuitive reporting systems, and etc.) required to maximize this invaluable resource ⁴⁶.

1.3.2. Data Abundance and Information Scarcity in Healthcare

Other industries (i.e. banking, retail, supermarkets, manufacturing, etc.) have been far more successful in harnessing the value from large-scale integration and analysis of their industry and organizational data ⁵. Healthcare is just getting its feet wet ⁴⁹. Although “healthcare is inherently an information based endeavor”⁵⁰, it is commonly known that healthcare organizations are data rich and information poor ⁵¹. Only the fraction of available healthcare data is being used for analysis and reporting. Information rests at the core of healthcare. Meaningful, well managed, easily accessible, and timely information is fundamental to the future of medicine, cost containment, improvement of patient quality care and outcome ⁵⁰. One solution is the effective use of health information technology (HIT), which can be defined as the “array of devices, procedures and processes for collecting, referencing and/or managing health information electronically ⁵⁰”. HIT encompasses broad categories of technologies including: electronic and personal health records, e-prescribing, computerized physicians order entry, clinical decision support, telemedicine, advanced medical imaging, smart pumps, bar coding devices and etc. HIT offers improvement by augmenting decision-making for healthcare professionals and assisting healthcare staff in patient care. Healthcare professionals, particularly physicians, are struggling with information overload. It is beyond human capability to continuously learn, remember, and apply the mounting evidence and the knowledge that is being generated on a daily basis. HIT aims to compensate for human limitations, enhance decision-making, improve delivery of care, and offer value for patients. The Health Information Technology for Economic and Clinical Health (HITECH) Act provided thirty billion dollars to promote “meaningful use” of EHRs through the Medicare and Medicaid electronic health record incentive programs ⁵²⁻⁵⁴. The incentive program “provides financial support for hospitals in the form of payments for the

meaningful use of health information technology through Medicare. Payments are made for adopting, implementing, or upgrading an existing EHR through the Medicaid program”⁵⁴. However, HIT is not without challenges. The implementation of HIT faces great challenges including: organizational, sociological, political, and technological. Fear of change, misaligned financial incentives, and performance limitations of the technologies themselves are among the challenges ^{50,54-58}.

1.3.3. Healthcare Digitization

Digitization of healthcare data and information management has mirrored the transition to computerization in other industries. The initial digitization phase of an industry is designing and using systems that specifically support transaction-based workflow and data collection ⁵⁹. The first wave of information technology in the 1950s was on the business and administrative side of healthcare using technology for the automation of repetitive tasks such as accounting and payroll, Healthcare payers and other industry stakeholders began to use information technology to process vast amounts of statistical data.

Twenty years later, the second wave started with a focus on digitization patient’s medical record, which began with the use of electronic medical record (EMR) systems in place of paper charts ⁶⁰. EMRs contained the medical and treatment history of patients in a single practice. The EMR advantages over paper record were considerable and included the ability to track patients over time, to easily identify patients due for preventative screening, and to monitor patients on certain parameters (i.e. vaccination, blood sugar, etc.) ⁶¹. However, major drawbacks were associated

with EMR systems. Some disadvantages which emerged included: inability to maintain longitudinal medical records of patients being cared by multiple care providers⁶²; limited ability to support coordination between clinicians and settings due to their design and lack of standardization of key data elements required for information exchange; difficulty in the management of information overflow; inability to adequately capture the medical decision making process and future care plans for care coordination; not designed for non-billable care coordination activities but rather for fee-for-service billable events (i.e. office visits, procedures, etc.)^{63,64}.

Relatively recent changes in healthcare models (e.g. Pay-For-Performance, Patient Centered Medical Home, and Accountable Care Organization) highlight the need to embrace technologies that facilitate easier retrieval and tracking of patient data with a focus on the longitudinal health of patients and contribute to the urgency for conversion from paper records and EMR to EHR systems. EHR systems are defined as “a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting. Included in this information are patient demographics, progress notes, problems, medication, vital signs, past medical history, immunization, laboratory data, and radiology reports”⁶⁴. EHR is designed to go beyond the standard clinical data collection in a provider’s office and is inclusive of a broader view of a patient’s care. EHR has all the EMR capabilities in addition to the accessibility to computerized records and the ability to share information with other healthcare providers (i.e. laboratory, specialists, etc.). EHR contains information from all clinicians involved in the patient’s care. EHR data “can be created, managed, and consulted by authorized clinicians and staff across more than one healthcare organization”⁶¹. EHR systems have many potential

capabilities, but three particular functionalities hold great promise in improving the quality of care and reducing cost. These include: clinical decision support (CDS) systems, computerized physician order entry (CPOE) systems, and health information exchange (HIE) ⁶⁵. EHR capabilities, in addition to the above particular functionalities, became the required criteria for “meaningful use” set forth by the Health Information Technology for Economic and Clinical Health Act (HITECH) of 2009 ^{53,65}. HITECH sought a means to address the alignment of economic incentives between payers and providers, to promote digitization, to strengthen healthcare delivery with seamless transfer of patient information, to provide transparency, and to improve the consumer experience. The enactment of HITECH led to widespread EHR adoption for sharing data and health information among members of workflow teams ⁵⁹. While digitization of patient and healthcare data is a necessary first step toward a data-driven care delivery, EHR alone is not enough. A platform that enables an enterprise-wide, consistent view of information that is aggregated from multitude of diverse and disparate data sources ⁶⁶ is required.

The third wave of digitization in healthcare focuses on the analysis of different aspects of data, information, and workflow that are reflected in the patterns of aggregated data ⁵⁹ in order to provide value. This phase of information technology focuses on the utilization of data to improve care. Without a way of organizing the clinical, financial, administrative, other healthcare related data into a single source of truth, a healthcare system cannot extract value from their data. In order to gain actionable clinical, financial, and operational insights, data from EHR and other internal and external source systems must be captured, aggregated, analyzed, and presented in a meaningful manner⁶⁰. This phase is characterized by the implementation and adoption of data repositories for aggregation of clinical data and building electronic data warehouses. To address

healthcare inefficiency and information deficiency, leading healthcare organizations have begun implementation of data repositories to aggregate clinical data and are building data warehouses to support the analytical needs of various initiatives, mandates, and programs, such as evidence-based practices, performance monitoring, quality improvement initiatives, outcome-based reimbursement models, and etc.

Analytics is defined as “systematic use of data and related business insights developed through applied analytical disciplines (e.g. statistical, contextual, quantitative, predictive, cognitive, other [including emerging] models) to drive fact-based decision making for planning, management, measurement and learning. Analytics may be descriptive, predictive or prescriptive ⁶⁷”. It enables healthcare organizations or hospitals to analyze a set of structured, semi-structured, and unstructured patients and healthcare data in search of valuable business information and insight. However, healthcare organizations are struggling to successfully manage the myriad stakeholders, regulations, and privacy concerns required to build fully integrated information technology systems ⁶⁰.

1.3.4. Big Data and Healthcare

The transition to the use of analytics unleashes the potential of “big data”. Big data in a healthcare setting would include data from the following sources: EHR; patient registries; CPOE systems, CDS systems, ambulatory and emergency care records; physicians’ written notes; prescriptions; medical imaging results; laboratory values; pharmacy records; insurance information; administrative data; machine generated/sensor data. Raw data or data with no

context has no value on its own. Without context, it is nothing but a meaningless cluster of numbers, letters, or words ⁶⁸. Transforming raw data into insightful information requires a team of experts with core skills of computer science, analytics and statistics, as well as domain knowledge, blended with strong communication skills ⁶⁹. Datasets must be identified, extracted, transformed, and linked together in order to be organized into a specific format, and be analyzed using techniques that provide answers to a specific set of questions. In healthcare, these basic steps alone pose a significant challenge. Often it is very difficult to identify and pin-point relevant and contextual data that can deliver value. One source characterized the process as finding “insight among the chaos” ⁶⁸. Other impediments to data management include: data volume, velocity, variety, variability, veracity ⁷⁰. Healthcare complexity and lack or limited data governance across healthcare organizations contribute to the problem. Yet another challenge is inadequate accessibility to raw data for utilization in analytics because of vendor restrictions, proprietary databases, lack of data integration or lack of appropriate data stores.

1.3.5. Healthcare Analytics Capabilities

There are challenges associated with use of analytics, including insufficient resources, inadequate technological infrastructure and a lack or limited understanding of the application of analytics to business, quality issues, and performance goals across organizations and stakeholders. Even though the availability of data in data repositories, data warehouses, or data marts has been a great starting point, data often remains unanalyzed and unreported among stakeholders for actionable outcome. Technologies must be evaluated for interoperability and compatibility, and for measures that are necessary in data standardization for future data utilities

⁷¹. Investments may be required to develop linkages across the source systems and data warehouses to leverage access to both administrative and clinical data. ⁷¹. Human capital is another facet of analytics that must be taken into account. There has been a limited supply of analytics talent. Analytics tools, technology, and infrastructure are necessary but the right people who understand the need, desired goals and objectives are critical for success. They deploy their knowledge, skills, and the appropriate tools to provide relevant and current information for information users, decision makers and other stakeholders at all levels in the organization. The lack of appreciation of the importance of an analytics team can be a problem. Many healthcare analytics teams become inundated by requests for a variety of reports, dashboards, and other analytics applications. The team becomes too involved in information development requests from users, rather than focusing on enhancing the analytics infrastructure and developing new tools of tactical and strategic significance ⁷². Furthermore, healthcare analytics is often impeded by regulatory concerns, resource constraints, and more importantly organizational cultures that are slow to trust and accept the role and importance of analytics ⁷³.

1.3.6. Evidence-Based Healthcare

The philosophical origin of Evidence-Based Medicine (EBM) dates back to mid nineteenth century ⁷⁴. It is defined as “conscientious, explicit, and judicious use of current best evidence in making decisions about the care of the individual patient” ⁷⁴. It is the translation and integration of clinical expertise, with the best available external clinical evidence from systematic research, and patients values into the decision making process, for the purpose of medical intervention ^{74,75}. Evidence-based practice is perceived by a majority as an important element in enhancing

patient quality of care by reducing unnecessary and inappropriate variations in medical practice⁷⁶⁻⁷⁸. Practice of EBM aims to keep medicine current with the latest findings⁷⁹. This involves frequent updates to clinical knowledge base (i.e., references that provide answers to clinical questions), dissemination of knowledge, and adherence to the latest acquired evidence⁷⁷. Such an approach faces significant and often justifiable barriers with regard to applicability, feasibility, implementation, and suitability of evidence-based practice⁸⁰⁻⁸².

1.3.7. Authority-Based to Evidence-Based Medicine Shift

EBM enhances a healthcare organization's ability to meet both its clinical and business needs. Challenges in the current healthcare environment, including the need to “cope with information overload, cost-control, and the public's impatience for the best in diagnostics and treatment”⁸³ make EBM a necessity. EBM employs clinical and financial logic to determine whether or not an action taken was beneficial^{83,84}. In the United States, the persistent increase in the cost of healthcare affects the cost of healthcare insurance. The cost of health insurance is rising faster than wages at a rate that is not sustainable⁸⁵. Cost-benefit analysis indicates that the quality of healthcare, measured in outcomes, safety, and service, has remained lower than expected⁸⁵. The value of healthcare delivered in the United States is lower than most developed nations in the world, when compared to relatively rich European countries such as France, Sweden, the United Kingdom, etc. Among individual states within the United States there is great variability in the value of healthcare delivered⁸⁶. On average only ten percent of the states provide high-value care, which has resulted in growing cost of care and poor outcome relative to developed countries on most dimensions of care²⁷. Ongoing cost-benefit analysis indicates increased

dissatisfaction with volume driven healthcare and authoritative-based medicine, which highlights the need for quality and cost control measures, and efforts to make the best use of finite resources.

1.3.8. Challenges to Evidence-Based Medicine Implementation

There has been a shift from authority-based medicine to evidence-based medicine over the past decade. The shift has introduced fundamental changes in the business of healthcare, in clinical practice, in health research, and in medical education ^{3,4}. Transition to the practice of EBM requires evaluation and acceptance of the possibility for improvement, and necessitates a process of life-long and self-directed learning. The shift to the practice of EBM has been highly praised but implementation of EBM has been very challenging and at times harmful ^{4,87-89}. The foundation of EBM rests on two core principles: an empirical approach to optimal clinical decisions regardless of pathophysiology (i.e. Does the bottom line show a gain or loss?), and its quantitative expression (How big is that gain or loss?) ⁹⁰. These two core principles require some mastery of epidemiology and statistics, in addition to comprehensive domain knowledge. These requirements have been repelled and resisted by many physicians and even many medical students who view them as too mathematical and remote from clinical practice ⁹⁰. Even though EBM has evolved to provide the skills needed to manage the potential information overload, it faces significant challenges. EBM challenges can be divided in four broad categories: volume of evidence, availability of relevant evidence, time and ability to interpret evidence appropriately, and translation of knowledge into clinical practice ⁴.

1.3.9. Volume of Basic Science and Clinical Research Evidence

The volume of basic-science and clinical research evidence is growing at a high rate. “Medicine must keep current with the research literature, and keeping current requires continuously updating the clinical knowledge-base”, which is defined as references that provide answers to clinical questions that can lead to healthcare decisions for patients ⁷⁹. A major barrier is the amount of clinical literature published in a variety of sources. The sheer volume of new articles published every day is growing exponentially, which makes it almost impossible for individual physician to remain up-to-date in their area of specialty, not even considering the latest evidence in related areas within their specialty. In 1992, around twenty English language clinical journals, with a focus on adult internal medicine published over 6,000 articles with abstracts. To keep up with the latest publications, an internal medicine physician would have had to read at least seventeen articles per day related to internal medicine alone to try to remain up-to-date ⁹¹. A Medical Subject Heading (MeSH) study in 1994, estimated that over 30,000 biomedical journals and over 17,000 new medical text books were being published annually. In 2004, Alper and colleagues quantified the volume of published medical literature potentially relevant to primary care to be 7,287 articles in a month and estimated it would require 627.5 hours per month for trained physicians in medical epidemiology to evaluate these articles for updating a clinical knowledge-base ⁷⁹. A 2005 study ⁹² on growth and decentralization of the medical literature examined data for all journal articles published from 1978 through 2001 which were available in 2003 on MEDLINE which is maintained by the National Library of Medicine (NLM). The study reported publication of 8.1 million articles during the time period. The results indicate that “between 1978 to 1985 and 1994 to 2001, the annual number of MEDLINE articles increased by 46 percent, from an average of 272,344 to 442,756 per year, and the total number of pages

increased from 1.88 million pages per year during 1978 to 1985 to 2.79 million pages per year between 1994 to 2001”⁹². The study reported the growth to be particularly concentrated in clinical research with an increased proportion of studies with human subjects. Medical Subject Heading changes indicated a shift from basic science headings toward clinical care and public health related topics i.e. public health, quality of healthcare, epidemiology, etc.⁹².

1.3.10. Availability of Relevant Evidence

To access the best available evidence it is essential to know: how and where to search and retrieve the best research studies; which databases are rich and reliable; and how to conduct a systematic and purposeful search strategy. Limited knowledge of the best available evidence may be one of the reasons behind inappropriate, wasteful, or controversial medical interventions. Guidelines are important in the practice of evidence-based medicine. EBM guidelines are defined as “systematically developed statements to assist the practitioner in making patient decisions for appropriate health care interventions for specific clinical circumstances”¹¹. Evidence-based guidelines can be synthesized from numerous sources with the overall goal to aggregate the best available evidence and use the conclusions to assist in clinical decision making⁹³⁻⁹⁵. There are challenges involved in the implementation of EBM in day-to-day practice. The volume of clinical research has been growing considerably, but optimal evidence is often not available for many physicians⁴. Systematic literature reviews have demonstrated that large numbers of studies are grossly inadequate, and are thus potentially misleading⁸³. A study by Haynes⁹¹ “estimated over 95% of articles in medical journals do not meet the minimal standard of critical appraisal.” Critical appraisal is a “systematic process used to identify the

strengths and weaknesses of a research article in order to assess the usefulness and validity of research findings”⁹⁶. The most important components of a critical appraisal are an evaluation of the appropriateness of the study design for the research question and a careful assessment of the key methodological features of this design. Other factors that must be considered include: suitability of the statistical methods used; interpretation of statistical methods; potential conflicts of interest; relevance of the research to area of practice⁹⁶ and study biases. To assess clinically meaningful patient outcomes, physicians require well-designed, large-scale clinical studies that are reflective of approaches or interventions in their particular domain.

1.3.11. Interpretation of Evidence

“The limited or lack of time and training on the part of well-intentioned physicians to critically and independently evaluate evidence threatens the very basis of EBM⁴”. Successful application of evidence-based practice depends on domain knowledge and the acquisition, appraisal, and applicability of clinical evidence⁹⁷. Physician and faculty clinicians often lack or have limited expertise in these key skills^{4,83,97} thus are unable to demonstrate the processes for other physicians, residents, and medical students^{97,98} in order to promote the practice of EBM. Many physicians gain limited knowledge and training as medical students in statistics classes or residency journal club, a common venue to learn basis of EBM)⁹⁷. “These forums can leave the impression that EBM requires hours of study to answer a single patient care question, a difficult time commitment for clinically active physicians, who therefore lose appraisal skills over time”⁹⁷. Required skills are fundamental in distinguishing between poorly designed or high quality research studies, and interpreting information when studies of equally high quality are conflicting in their findings⁴. In addition to a lack of the required skills, there is resistance within

a subset of clinicians who prefer to exclusively consult colleagues for less familiar diagnoses rather than do research frequently encountered patient problems. Additional obstacles include, aversion of physicians and medical students to learning and understanding statistics and epidemiology ⁹⁰. There is a growing volume of evidence regarding the overall difficulty of translating the acquired EBM knowledge into behavioral change ⁹⁹.

1.3.12. Translation of Knowledge into Clinical Practice

“Assuming the volume of published studies, availability of information, time, and ability to independently and critically evaluate evidence, translation of evidence to practice may still be challenging” ⁴. The preponderance of research evidence is in the form of clinical trials and observational studies which pose advantages and limitations for translation of the studies’ outcomes ⁴. The designs of clinical trials are intently focused on specific patient populations who are subjected to strict monitoring parameters, which create a somewhat artificial environment. Consequently, translation of the outcome becomes difficult and may not be reflective of the majority of patients who would normally be seen in a clinical setting and be evaluated with the same stringent parameters ⁴. Observational studies answer many human health research questions and provide great contributions to medical knowledge. However, observational studies potentially have inherent selection bias based on age, socioeconomic status, information bias, measurement errors, confounders, etc. and have a limited level of clinical details, which makes the interpretation and translation of outcome difficult to answer relevant clinical questions ^{4,100,101}. Given these challenges, it is naïve to assume that evidence is the only impediment to evidence-based clinical decision making. There are a multitude of other factors such as patient preferences, social circumstances, presence of disease, disease-drug and drug-drug interactions,

clinical conditions, etc. that influence clinical decision making ⁴. Besides the quality of the evidence itself, there are other barriers to surmount in order to provide the most consistent and best possible care to patients ¹⁰².

1.3.13. Continuous Quality Improvement Barriers to Evidence-Based Practice

Outside of clinical and patient specific issues there are many other factors that play a critical role in the translation of knowledge into informed clinical practice. The factors can be broadly categorized at the individual and the institutional levels ^{4,102}. There are four major interrelated dimensions: strategic, cultural, technical, and structural with an effect both on individual and institutional levels ^{102,103}. “The strategic dimension includes the activities and processes that are most important to the organization and provide greatest opportunities for improvement, such as vision, budget, priorities, and long-term strategy. The cultural dimension represents the organization’s beliefs, values, norms, and behavior. The technical dimension encompasses training and information infrastructure. The structural dimension refers to the ways that knowledge is acquired and dispersed throughout the organization” ^{102,103}. An individual may practice EBM as a means to provide better care for patients or as a result of interest in a particular intervention or condition ¹⁰². The institution may be inclined to practice EBM as means to maintain “magnet accreditation, attract more payers, or to be eligible for incentives” ¹⁰². The challenge arises when “individuals or institutions do not know about, nor see the value in practicing EBM” ¹⁰².

1.3.14. Outcome Driven Healthcare

As part of the transformation of the healthcare system, the context in which physicians and other healthcare providers deliver care has also shifted ¹⁰⁴. The reshaping of the healthcare landscape has led to the trend toward physician employment by healthcare institutions and consolidation of healthcare systems ¹⁰⁴⁻¹⁰⁶. Fee-for-service reimbursement models encouraged fragmented healthcare delivery systems. Changes and reform in payment policies have encouraged a shift to a system that encourages integration and care coordination that holds physicians and other healthcare providers accountable for patient outcomes and costs ¹⁰⁴. It is unclear whether the changes in incentives and payments will result in improved quality of care, enhanced health outcomes, and lower cost for patients and healthcare organizations because of the potential disconnects in organizational and individual physician incentives ¹⁰⁴. Many payment reforms such as shared savings and various risk-based models are targeted at healthcare organizations. However, within these healthcare organizations, countless decisions are being made daily by physicians, nurses, and other healthcare providers who will predominantly determine organizational performance ¹⁰⁴. Although bundled payment, shared savings, and other reform initiatives may have an effect on reducing the proportion of payments linked to volume at the organizational level, “healthcare providers are still being paid to do more” ¹⁰⁴. “The providers are often largely being compensated by their organizations based on productivity” ¹⁰⁴. To achieve alignment, healthcare organizations, ACOs, and other healthcare delivery systems must redesign financial incentives to link payments to patient outcomes. The size and timing of the reward play a critical role in how individuals respond ¹⁰⁷. Shortening the lag time between delivered care and rewards improves saliency ¹⁰⁸. Strategies include decoupling outcome driven financial incentives from other usual compensation ¹⁰⁹, and evaluating, timing, frequency, size, and other

characteristics of incentives, including how to link them to a specific set of performance measures¹⁰⁴. Non-financial incentives that appeal to intrinsic motivation also have an influence on behavior change^{110,111}, including the desire to do a challenging task in order to positively impact the lives of others¹¹², peer comparison (i.e. quality report cards)¹¹³, and putting individual healthcare providers' goals in writing¹¹⁴. As the number of hospital and healthcare-organization-“owned” physicians and practices increases, (significant increase was observed from 16 percent in 2007 to 29 percent in 2012)¹¹⁵, the need to align organizational and individual provider incentives will likely increase in the future¹⁰⁴. Current evidence on the use of financial and non-financial incentives to drive “quality improvement in healthcare has been mixed at best”¹¹⁶.

1.3.15. Healthcare Organizations Improving the Value of Care Delivered

In order to improve the effectiveness and value of care delivered, healthcare organizations must build their capacities for “ongoing study and monitoring of the relative effectiveness of clinical interventions and care processes through expanded trials and studies, systematic reviews, innovative research strategies, and clinical registries (They must also improve) system’s ability to apply what is learned from such study through the translation and provision of information and decision support”¹¹⁷. For a healthcare organization to thrive, it must successfully implement a learning healthcare system. This is defined as a system that is designed to generate and apply the best evidence for the collaborative healthcare choices of each patient and provider, to derive a process of discovery as a natural outgrowth of patient care, and to ensure innovation, quality, safety, and value in healthcare¹¹⁸. It must incorporate the best available scientific evidence as it seeks to improve the quality of patient care and outcomes, to quantify and report

on performance, and to design and implement a feedback mechanism to enable learning from various experiences and interventions. To achieve this high level of performance a higher level of organizational capacity is essential. This requires a robust information technology infrastructure and a new breed of skills such as informatics and performance management expertise, in order to achieve clinical integration ¹¹⁹. Such a high level capacity currently is not present in most healthcare settings ¹¹⁹. Given the complexity of modern medicine, information technology plays a central role in the redesigning of the healthcare system if a substantial improvement in quality is to be achieved over the coming decade ¹²⁰. Information is critical to a learning healthcare system; health informatics focuses on what, how, and why of managing information ¹²¹. The ultimate goals of health informatics approaches are to streamline the processes of patient care, provide clinicians with accurate information in a timely manner, educate providers, healthcare consumers and stakeholders, improve the quality of care, and provide the means to identify cost saving measures ^{122,123}

Healthcare organizations need to leverage their information technology infrastructure and informatics capability to: provide the best available evidence ¹²⁴; use organizational culture to effectively foster the intrinsic motivation of physicians to ensure providers “buy-in”¹⁰⁴; develop effective educational methods (i.e. systematic practice-based interventions as opposed to continuing medical education); effectively incorporate evidence-based knowledge into day-to-day operations¹²⁵; and align financial and non-financial incentives to promote environments that encourages effective professional behavior¹⁰⁴. This will best encourage and alter the behavior and practice of their frontline healthcare providers in a way that enhances their performance and outcomes. While any single intervention may have relatively minor impact, over time the

combination of various incremental steps can lead to significant strides in improving quality of care and reducing cost for both patients and healthcare organizations¹⁰⁴.

1.4. Application of Evidence-Based Medicine in Transfusion Medicine

1.4.1. Rationale and Need

To date, healthcare organizations in the United States have under-estimated and overlooked the cost of red blood cells (RBC) transfusion as part “doing business”^{21,126}. As a result, the true cost of transfusions, both to patients and to healthcare organizations, has been widely unappreciated^{21,127-129}. In a 2010 study, accurate measures were employed that revealed the cost of a transfusion ranging from \$522 to \$1,183 per unit depending on geographic location (these figures do not take morbidity into account)²¹. Beyond the cost of transfusion, each unit of RBC has inherent risks, which are potentially associated with increased cost of care. In particular, liberal transfusion practices that occur at higher hemoglobin levels can increase the cost of care more than those given at lower hemoglobin levels¹²⁶.

In transfusion medicine, as in other areas of medical practice, there is a gap between the latest knowledge and current physician practice. Transfusions of blood products, which include whole blood, RBC, platelets, plasma, and cryoprecipitate, are a critical component of clinical care. In the United States, RBC transfusion is one of the most frequent procedures performed in hospitals, with one in ten inpatients receiving one or more units of blood¹³⁰. In 2011, five million patients received RBC transfusions; 13.7 million RBC units were transfused¹³¹. In the latest statistical reports (2010 and 2011) by Healthcare Cost and Utilization Project (H.CUP), blood transfusion is among the top ten prominent coded procedures in United States hospitals as

evidenced in discharge records. In the same report, the cost of transfusion accounted for ten to fifteen billion dollars annually ^{12,13,132}. In a recent blood transfusion cost analysis study, the actual cost of RBC transfusion was determined to be 3.2 to 4.8 fold higher than previously estimated ²¹. The under- representation in the cost of blood transfusion is a result of an incomplete accounting of the required resources and the associated activity-based costs ²¹. The factors not fully taken into account include, but are not limited to, patient testing, pre-transfusion preparation, transfusion administration, follow-up, and long-term tracking of patients ¹³³⁻¹³⁵. The actual cost of a blood product unit and transfusion related activities accounts for a significant portion of hospital spending. ranging from 1.6 – 6.0 million per hospital surveyed ¹³⁶. Product acquisition costs contribute only 21 to 32 percent to transfusion related expenditure. Blood unit costs vary geographically with regional variation. Mandatory, transfusion-specific, informed consent in the United States accounts for 1.2 to 2.5 percent of total transfusion-related expenditures ²¹. Materials plus fixed and variable labor costs contribute approximately 18 percent and indirect overhead (including equipment, utilities, nonprofessional personnel, and property) is estimated to contribute 46 percent to the total cost of cost of blood product transfusion ^{21,137}. As a result, total expenditure and utilization varies by 2.3 fold across healthcare organizations. The spending variation cannot be explained entirely by hospital size, number of beds, or surgical volume ²¹. Hospitals' total cost of blood annually has been largely driven by the transfusion rate, which includes factors such as case-mix index; proportion of surgical patients transfused, number of RBC units per patient transfused, and practice differences ^{21,138}. These factors have contributed to variation in transfusion rates among hospitals ¹³⁸. Lower transfusion rate has not been associated with worse outcomes ¹³⁸. Reducing either of these factors has the potential to reducing costs dramatically ²¹.

1.4.2. Current Practices

As commonly as transfusions occur in the United States, one may assume that physicians practice transfusion medicine based on strict standard guidelines. However, the efficacy of blood product transfusion is poorly understood among practicing physicians¹³⁹⁻¹⁴³. A broad variation exists not only with regard to what type of blood components to transfuse and how much, but also with regard to whether to transfuse at all¹⁴⁴⁻¹⁴⁹. “For 100 years, we’ve assumed blood transfusion is good for people, but most of these clinical practices grew before we had the research to support it¹⁵⁰.” “The current transfusion triggers were established over sixty years ago at the time when transfusion medicine was still in its infancy”¹⁵⁰. Over the past fifteen years, scientific studies have highlighted the overuse of blood transfusion based on outdated transfusion triggers and guidelines of practice¹⁵¹⁻¹⁵⁵. A recent systematic review of 494 studies on the appropriateness of allogeneic RBC transfusion has illustrated that up to 59 percent of transfusions are unnecessary¹⁴², providing either no benefit, or heightened risk of complications for patients, and increased cost of care^{142,156}. Additionally, published studies have associated blood transfusions with negative outcomes including longer length of stay, increased rate of infection, postoperative complications, myocardial infarction, pulmonary edema, and mortality^{131,157}. Transfusion reaction is defined as any adverse event or complication that occurs in relation to the transfusion of a blood component^{152,158}. Historically, infections were considered the main risk, but because of the abundant donor testing and thorough donor screening, the risk of acquired infectious diseases through transfusion has declined drastically^{159,160}. The infectious

complications and the current infectious risks of blood transfusion are represented in Table 1 ¹⁶¹⁻
178.

Table 1 - Infectious complications and risks of blood transfusion, 2007 to 2012.

Agent	Risk Per Unit Transfused
Parvovirus B19 (erythrovirus)	Unknown; about 12 cases reported in the literature
Babesia	1:20,000
Bacteria (platelets)	1: 5,000 (tested)
Bacteria (RBCs)	1:500,000
Hepatitis A virus	1:1 million
Hepatitis B virus	1:850,000 to 1:2 million
Hepatitis C virus	1:1,150,000
HIV (Human Immunodeficiency virus)	1:2 million
Human T-lymphotrophic virus	1:200,000 to 1:500,000
Malaria	1:1,000,000
West Nile virus	Unknown but varies by season; about 11 cases reported in the literature since 2003

With the decrease in rate of transfusion-transmitted infectious diseases, non-infectious serious hazards of transfusions have emerged as the leading complication of transfusion ¹⁶. Research has shown, a patient is 1000 fold more likely to experience non-infectious complications than an infectious complication of transfusion ¹⁷⁹. Some of the more common non-infectious serious hazards of transfusions include transfusion reactions such as hemolytic, febrile, septic, allergic, urticarial, and anaphylactic. Transfusion of the incorrect product to the incorrect recipient is another potential hazard. Other problems include transfusion-related acute lung injury (TRALI), transfusion associated circulatory overload, post-transfusion purpura, transfusion-associated graft versus host disease, microchimerism, transfusion-related immunomodulation, alloimmunization, metabolic derangements, massive coagulopathic transfusion complications, red cell storage lesion complications, over or under transfusing complications, and iron overload ¹⁶. Table 2 lists

the non-infectious complications and the current non-infectious risks of blood transfusion with associated clinical signs and symptoms ¹⁶¹⁻¹⁷⁸. An analysis by the Food and Drug Administration (FDA) showed hemolytic transfusion reaction alone has accounted for more than twice of transfusion-associated fatalities compared to all infectious hazards combined ¹⁸⁰. Meta-analysis from risk-adjusted observational studies has shown RBC transfusions are associated with a 69 percent increase in mortality and 88 percent increase in morbidity ¹⁸¹. The major concern now is the non-infectious hazards of blood transfusion.

Table 2 - Non-infectious complications and risks of blood transfusion, 2007 to 2012.

Adverse Outcome	Risk Per Unit Transfused	Clinical Signs & Symptoms
Acute hemolytic	1:40,000 to 1:70,000	Chills, fever, pain at infusion site, hemoglobinuria, shock, acute renal failure, flank pain, DIC
Allergic - simple	1:100 to 3:100	Flushing, hives, itching
Allergic - severe	1:20,000 to 1:50,000	Hypotension, respiratory distress, wheezing, local edema
Transfusion associated circulatory overload (TACO)	1:100 to 11:100	Dyspnea, hypertension, pulmonary edema
Delayed hemolytic	1:5,000 to 1:11,000	Drop in hemoglobin, increased indirect bilirubin, new RBC antibodies
Febrile non-hemolytic	1:100 (prestorage leukoreduced products)	Fever with greater than 1°C change, chills, rigors
Graft versus host disease	Rare	Rash, diarrhea, hepatitis, pancytopenia
Transfusion-related acute lung injury (TRALI)	8:100,000	Hypoxemia, dyspnea, hypotension, non-cardiogenic pulmonary edema

1.4.3. Need for Change in Transfusion Medicine Practice

It has been more than a decade since the publication of the landmark study “Transfusion Requirements in Critical Care (TRICC) trial” ¹⁴⁸ and many others studies ^{140,142,149,155,182-184} supporting the restriction of RBC transfusions for patients ¹⁸⁵. Since then, there have been some

reports indicating improvements in transfusion practices, mostly with regard to reduced hemoglobin thresholds at which patients are transfused ¹⁸⁶⁻¹⁸⁸). Nonetheless, the overall use of allogeneic RBC transfusions in clinical practice remains relatively high and still varies widely among many centers and practitioners ^{185,189-191}. One underlying issue is that many physicians were trained before transfusion research and evidence were available regarding transfusions. For example “the leading risk factor for perioperative transfusion is preoperative anemia”. Preoperative anemia can be feasibly corrected with advanced testing and preoperative interventions such as vitamin B12, folic acid, erythropoietin ^{154,192,193}. Historically, some physicians have been taught liberal transfusion practice and to follow the maxim “if you are going to transfuse, why not give two” ^{15,194,195}. Now, however, numerous research studies have examined RBC ^{148,149,155,162,182,183,196,197} and platelet use ^{27,198-202}. This has led the American Association of Blood Banks (AABB), the Joint Commission, the World Health Organization, and other groups, to publish guidelines to help guide evidence-based practice in transfusion medicine ^{15,162,203,204}. Nonetheless, many clinicians are slow to change ¹⁵, and some are even skeptical without seeing hard evidence, such as individualized data driven reports, information on latest research evidence in practice, reports on their individual practice and the practice of their peers.

1.4.4. Scrutiny of Transfusion Efficacy

Over the past two decades, the efficacy of transfusion, particularly RBC, has been challenged. Recent clinical studies have indicated that transfusion of critically ill patients with traditional hemoglobin level triggers i.e. to maintain hemoglobin levels in the range of 10.0-12.0 g/dL, may

not improve patient outcomes^{153,205-208}. Restrictive RBC transfusion practices, in which RBC transfusions are given at lower than “traditional” hemoglobin levels i.e. to maintain hemoglobin levels in the range of 7.0-9.0 g/dL, have been proven safe in multiple randomized controlled trials^{139,140,158,209}. Given that RBC transfusion is one of the top five overused procedures²¹⁰ with its increased risks and costs, there is a growing recognition of the need to implement strategies to reduce transfusions. The concept of Patient Blood Management (PBM) has evolved as a strategy to promote a proactive rather than reactive approach.

Even though, over the past twenty years, “high-level research in transfusion medicine has been undertaken at the same rate as in all other medical specialties in terms of numbers of randomized controlled trials and meta-analyses”²¹¹, there is a considerable variability that exists in transfusion practices within different groups of patients^{142,149,212-217}, including critically ill^{205,218-220} and acutely ill^{182,221-223} hospitalized patients, obstetric patients^{224,225}, and patients undergoing various surgical procedures (i.e. cardiac^{146,226-228}, hip and knee²²⁹⁻²³², neck and spine^{188,233-235} surgeries. Variation in transfusion practices has been observed nationally among physicians practicing in the same geographic region or even in the same healthcare institution performing the same procedures on patients but producing different rates of transfusion and, consequently, varying outcomes. The decision on whether or not a patient receives a blood transfusion depends on each physician’s training on the clinical indication of anemia, the tolerance level of anemia, the patient’s physiological condition and the level of need for correction of the anemia^{217,236}. In addition, since it is known that untreated anemia can have adverse effects, physicians are often prompted to transfuse even if the benefits of transfusion are not entirely certain²³⁷. Another significant contributing factor is inadequate formal training of clinicians on the clinical

indications for blood transfusion therapies during their time at medical school²³⁸⁻²⁴⁰. Audits and review of clinical transfusion practices have consistently demonstrated deficiencies in knowledge and practice of blood product transfusion, which impact patient safety and outcomes. Studies²⁴¹⁻²⁴³ on the effect of formal educational programs on transfusion safety have identified deficiencies in the practice of transfusion medicine, including inappropriate transfusion prescribing, improper administration of blood products, improper documentation, and inadequate identification of potential transfusion recipients.

1.4.5. Patient Blood Management

Patient Blood Management (PBM) is defined as “timely application of evidence-based medical and surgical concepts designed to maintain hemoglobin concentration, optimize hemostasis, and minimize blood loss in an effort to improve patient outcome”²⁰⁴. Further it is defined as “an evidence-based, multidisciplinary approach to optimize the care of patients who might need transfusion.” It encompasses all aspects of “patient evaluation and clinical management surrounding the transfusion decision-making process, including the application of appropriate indications, as well as minimization of blood loss and optimization of patient red cell mass”²⁴⁴. The concept of PBM promotes a proactive rather than reactive approach to the practice of transfusion medicine addressing anemia, coagulation conditions, and blood conservation, with a focus on the practice of restrictive approaches in order to “reduce or eliminate transfusions when applied as a multimodality approach”¹²⁷. The goal of PBM is to reduce unnecessary or inappropriate resource utilization and improve patient outcomes^{245,246}. PBM is rooted in an evidence-based approach to medicine.

1.4.6. U.S. Department of Health and Human Services Recommendations

The United States Department of Health and Human Services (HHS) Advisory Committee on Blood and Tissue Safety and Availability has recognized the significant risks associated with transfusions, the wide variability and deficiencies in transfusion practices, the changing patterns of demand for blood, and the documented success of PBM programs. Therefore, the Advisory Committee on Blood and Tissue Safety and Availability has made the following recommendations:

- Identify mechanisms to obtain data on PBM, utilization of transfusion and clinical outcomes.
- Support, develop, and circulate national standards for blood use recognizing the value of patient management, blood conservation, and conservative blood use.
- Establish transfusion expertise integral to transfusion practices in hospitals and other patient care settings.
- Establish metrics for good practices of blood use and PBM.
- Advise the Office of the National Coordinator for Health Information Technology on the need to integrate PBM and blood utilization into electronic health records.
- Promote education of medical students and practitioners on optimizing PBM and the use of transfusion, and elevate awareness of the essential role of PBM in the quality and cost-efficiency of clinical care.
- Promote patient education about the risks, benefits and alternatives of transfusion to promote informed transfusion decision-making.
- Support demonstration projects on PBM.

- Support research on non-invasive clinical measures to define indications for transfusion, e.g., ischemia, hemostasis, platelet function, and patients' functional status²⁴⁷.

1.4.7. Recommendations of Health Organizations

The World Health Organization (WHO) followed the HHS recommendations with the adoption of declaration 63.12 “addressing the global importance of incorporating PBM into clinical practice as a patient safety measure ²⁴⁷”. In conjunction with these activities, the American Medical Association (AMA) and the Joint Commission have introduced Patient Blood Management Performance Measures to help evaluate the appropriateness of transfusions as a continuous quality indicator ²¹⁰. Establishing an evidence-based approach to blood utilization has the potential to encourage appropriate transfusion practice and simultaneously reduce blood utilization, while improving patient outcomes and substantially lowering healthcare organization expenditures ^{142,164,246,248-251}. Such an approach conserves a precious resource and permits the same blood products to be re-directed to other patients who are in true need of the supply within or outside the hospital ^{251,252}.

1.4.9. Implementation of a Patient Blood Management Program

To date, practice of transfusion medicine has followed the approach of traditional medicine, where the decision-making relied more on physicians' background knowledge, clinical experiences, consultation with senior physicians and textbooks ⁹³. Even though some of the basic principles behind evidence-based medicine have been known for many years, the concept and approach to integrating evidenced-based decision making into clinical practice on a day-to-day basis have only evolved over the past twenty or more years ⁶. The emergence of compelling

evidence of the benefit and the need to change has begun to change the landscape of transfusion medicine. The shift is to base decision making on evidence-based practice, and to promote a convergence of both individual clinical expertise and the best available evidence^{6,93,253}.

1.4.8. The Need to Promote EBP in Transfusion Medicine through PBM

A 2011 editorial on blood transfusion practices stated, “Possibly the major obstacle to making transfusion practice more consistent and in line with published guidelines and evidence-based medicine is the overall lack of knowledge regarding transfusion medicine shared by clinicians across specialties as evidenced by published data. This evidence would seem to indicate that medical education in transfusion medicine continues to lag behind. Thus, no matter what the conclusions of future studies on transfusion efficacy turn out to be, there will be little impact on blood utilization overall if we continue to fail to educate the end users²¹⁷”. Transfusion triggers cannot be precisely defined and there are questions as to whether a non-bleeding patient will benefit from blood transfusion, particularly a patient whose hemoglobin concentration is in the middle range of published guidelines, i.e. between 7.0 and 10.0 g/dL [257]. This has led to inconsistent transfusion practices and often inappropriate transfusions. There is a particular need to bridge the gap between evidence and transfusion medicine practice.

1.4.10. Patient Blood Management Implementation Requirements

Organizational Structure and Engagement

There is mounting physiological, medical, ethical and financial evidence that a change in physician transfusion practices is essential to ensure patients’ improved quality of care and

outcomes. Implementation requires a top-down approach. PBM challenges the training of clinicians, which makes the effort difficult to embrace ²⁵⁴. Endorsement from top senior executives is essential to prioritize, determine urgency, and allocate resources (i.e. human, financial, and information technology services) in order for the program to successfully roll-out across different hospitals ²⁵⁵. The level of support and engagement provided by hospital executives can greatly impact the success of the program both positively or negatively. In order to engage physicians and other clinical providers, it is essential for executives to be educated on the evidence supporting PBM, so they can speak knowledgeably to the initiative. Implementation of PBM involves and requires diverse groups of stakeholders including: administrative (C-suite executives, senior vice presidents, vice presidents, department heads, and quality teams), clinical (multispecialty [i.e. surgery, anesthesiology, intensive care, etc.], multidisciplinary [medical, nursing, perfusion, etc.], laboratory [pathology, blood bank, and transfusion service]), and information technology and informatics. Healthcare organizations or hospitals have to overcome significant practical and political challenges to effectively implement PBM programs at their facilities.

At its core, PBM aims to re-educate healthcare providers on the latest evidence-based research in order to promote the change to best-practices. Re-education of physicians with ingrained transfusion practices is difficult. PBM principles apply to many different medical disciplines and affect many patients' clinical care and treatment plans which makes implementation of a robust and scalable PBM program healthcare system-wide or hospital-wide very challenging. The program requires a Transfusion Medicine Medical Director who is knowledgeable of the intricacies of transfusion medicine and a PBM Committee whose members are tasked with

driving implementation of the program in their area of discipline. The Committee should consist of respected stakeholders and physician champions from different medical disciplines to illustrate the legitimacy of the initiative within a hospital ^{255,256}. The committee must be convinced of the value of the program, believe in the principles of PBM and trained in their roles, responsibilities and the vision for the program. It is essential for senior executives to work closely with the PBM Committee as well as with quality and IT personnel to assess the hospital areas in greatest need of improvement from a PBM approach and to ensure that the planned initiatives are relevant for surgical and non-surgical physicians within each discipline ²⁵⁶.

Prior to implementation, assessment and base line analysis must be conducted to evaluate current practice and to identify areas of focus that should be communicated to all stakeholders. Current state and continuous analysis of transfusion medicine practice requires: a deep knowledge of transfusion medicine; familiarity with the context and type of data and information that is required for assessment; knowledge of the various health information systems in play; and a mechanism for bringing fragmented data and information together for coherent reporting and evaluation. The significant challenge associated with this analysis will be discussed in depth. PBM requires transfusion medicine expertise to routinely evaluate and examine the latest transfusion medicine evidence and guidelines for different disciplines, in order to synthesize and communicate educational materials to relevant medical disciplines. Reports must be developed based on hard data and evidence to provide physicians and other clinical professionals with information about their practice relative to current evidence-based best-practice guidelines. Evaluation and analysis of transfusion medicine practice and communication of the progress in outcomes are the key factors in the success and sustainability of PBM program.

Data, Analytics, and Reporting

Identification, extraction, aggregation, and analysis of contextual data are critical in providing the meaningful information needed to raise awareness and empower informed decision making. Transfusion related data is captured in different formats and in several diverse and disparate source systems both on the administrative and the clinical side. This impedes the aggregation of the minimum data sets required to feed the measures and indicators, thus hinders reporting and analysis. In transfusion medicine, in order to provide a comprehensive view on performance of a healthcare organization and individual physician practice, data from both clinical (clinical service lines, laboratory, pharmacy, transfusion service, etc.) and administrative (billing, finance, information services, credentialing, etc.) departments are required. Healthcare organizations have always generated a multitude of data including: administrative information, clinical indicators, procedural indicators, provider and staff measurements and interpretations and equipment readings. However, most of the generated data is stored in hard copy form, outdated legacy platforms, or siloed information systems. Even though the aim of digitization of healthcare is to transition from fragmented healthcare delivery systems to integrated healthcare models, challenges remain. Even as EHRs are becoming the norm as a way to provide fast and easy ways to share data and make information accessible to more members of patients' care delivery teams, many components of healthcare organizations and hospitals still operate on diverse and disparate departmental information systems with inefficient and ineffective data and information gathering and reporting systems ²⁵⁷. While each department and branch of operations has unique needs, siloed technical and information ecosystems compromise cross departmental data aggregation, reporting, and analysis and foster fragmented clinical and administrative decision-making. Transfusion practice reporting and performance tracking is often not available. If it is available,

it may not contain the detailed level of information necessary to highlight trends in an individual physician's practice. Manual data collection and analysis is not feasible or sustainable. It requires alignment of staff and resources in order to accomplish an arduous process on an ongoing basis. The process is time consuming, challenging, inefficient, and costly ²⁵⁸.

Presentation of Actionable Information

The meaningful presentation of actionable information must be provided on a routine basis to guide transfusion practice and encourage sustainable behavior change. The information should provide a baseline of current practice against which to measure progress in future improvement initiatives. Many healthcare organizations lack the reporting mechanisms. The lack of necessary information negatively impacts the work of the PBM Committee, the Transfusion Medical Director, and the physicians because they are unable to adequately monitor the manner in which transfusion medicine is being practiced. To date, monitoring physicians' transfusion practice has been primarily achieved through individual chart reviews by a transfusion committee to ensure appropriateness of transfusions as determined by the hospital's medical staff ^{238,259}. However, the common practice of individual chart review frequently fails to recognize the forty to sixty percent ^{142,260} of inappropriate and non-beneficial transfusions that occur in almost every hospital ²⁵⁹. There are many reasons that individual chart review is not as effective as it is intended to be ²⁵⁹, including:

- the underlying complexities surrounding transfusion medicine;
- lack of or limited subject matter expertise;
- limited knowledge of the intricacies of transfusion practice;
- lack of awareness of the latest evidence and best practices;

- outdated and inappropriate transfusion criteria and guidelines for evaluation of transfusions, e.g. using a single lab value as a reference point for determination of appropriateness, in contrast to a comprehensive evaluation of the patient's condition;
- limited or lack of a “big-picture” view of hospital and provider transfusion practice;
- uncompensated physicians' review time;
- organizational culture and disciplines;
- reviewer bias, particularly when physicians review the work of other physicians with whom they may have work, economic, political, social, and referral relationships.²⁵⁹

1.5. Current Approaches

Data gathering from diverse and disparate systems within a healthcare organization is a major impediment to implementation of an evidence-based PBM programs. Some forward-looking healthcare organizations have been relying on manual processes to capture transfusion data and report information²⁵⁸. This approach is highly redundant and time-consuming and introduces great potential for human error. It is important to note that manual analysis and review are taking place in healthcare settings with diverse health information ecosystems, where interoperability and data integration is very limited or non-existent. In such environments, data is stored in multiple disparate systems, with limited or lacking interface capabilities with other systems. As a result, one must work with fragmented data which can create an incomplete view of a clinical event. This method of monitoring can create conflicting perspectives on the type of data necessary to capture and report²⁵⁸. Such an approach may also introduce tension between colleagues, which can negatively impact the benefits of monitoring efforts and affect both quality and compliance measures. Traditional manual processes are resource intensive and most likely

require multiple full-time equivalents to handle the laborious task. Therefore, this approach is not feasible and sustainable on an ongoing basis²⁵⁸. To date there is no framework for efficiently accessing relevant data and information in a coherent, contextual manner, in order to learn about and evaluate transfusion practices and monitor providers' transfusion behavior in an organization. Bringing together data from diverse and disparate systems remains a major impediment to the practice of evidence based transfusion medicine practice.

1.6. Conclusion: Application of an Evidence-Based Data Analytics Framework

Healthcare is undergoing a paradigm shift from authority-based to evidence-based medical practice in response to current clinical, financial and regulatory challenges. Significant hurdles face organizations as they struggle to implement successful, scalable evidence-based programs^{4,93,261-263}. A great deal of attention is being paid to evidence-based practice in the area of transfusion medicine with the implementation of Patient Blood Management programs. Despite the fact that blood transfusion is among the top ten most prominent coded procedures according to U.S. hospital discharge records^{12,13}, the efficacy of blood product transfusion is poorly understood among practicing physicians^{18,152,181,222,228,264,265} making transfusion medicine an area ripe for improvement through evidence-based approaches.

This study demonstrates the effectiveness of an evidence-based approach to transfusion medicine practice that can be applied to many areas of medical practice. It takes into account the clinical, administrative, cultural and technical issues that make the implementation of an evidence-based program so challenging. The study focuses on reducing the inappropriate practices in transfusion

medicine, particularly in the transfusion of allogenic RBC in healthcare institutions. A framework was developed that promotes the use of evidence-based guidelines by:

- Obtaining broad organizational engagement;
- Obtaining physician engagement and attain accountability;
- Incorporating latest evidence and best practices into medical practice;
- Identifying, extracting, and aggregating contextual data from diverse and disparate source systems;
- Identifying measures and indicators to track transfusion behavior in accordance with the latest evidence;
- Developing a performance management system;
- Transforming physician specific data into meaningful information;
- Providing current targeted information to physicians and administrators;
- Enhancing awareness and education;
- Developing a feedback mechanism;

This study demonstrates the importance and the effectiveness of the tight integration of these elements to promote evidence-based decision-making at the point of care. The approach bridges the gaps that exist between the latest medical knowledge and current physician practice and has the potential to improve the quality of patient care, improve outcomes and decrease the cost of care.

Chapter 2: Literature Review

2.1. Healthcare Industry and Transformation of Clinical Practice

2.1.1. Evidence-Based Practice as a Way to Improve Quality of Care

Healthcare organizations are being pushed in the direction of evidence-based practice as a way to improve quality and patient safety. Research has constantly shown clinical decisions are rarely based on the most current and best available evidence. Rosenberg states in a 1995 article that “For decades people have been aware of the gaps between research evidence and clinical practice, and the consequences in terms of expensive, ineffective, or even harmful decision making”²⁶⁶⁻²⁶⁸. The current magnum opus of evidence-based practice is the book published by Sackett and colleagues in 2000 titled *Evidence-Based Medicine: How to Practice and Teach EBM*⁸⁴. The book defines EBM as “the integration of best research evidence with clinical expertise and patient unique values and circumstances.” It also provides definitions for: (i) best research evidence as “clinically relevant research, sometimes from basic sciences of medicine, but especially from patient-centered clinical research into the accuracy and precision of diagnostic tests, the power of prognostic markers, and the efficacy and safety of therapeutics, rehabilitative, and preventative strategies”; (ii) clinical expertise as “the ability to use clinical skills and past experiences to rapidly identify each patients’ unique health state and diagnosis, their individual risk benefits of potential interventions, and their personal values and expectations”; (iii) patient values as “unique preferences, concerns, and expectations each patient brings to clinical encounter and which must be integrated into clinical decision if they are to serve the patients”; and (iv) patient circumstances as “their individual clinical state and the clinical setting”⁸⁴. Once “the four elements are integrated clinicians and patients form a diagnostic and therapeutic alliance, which optimizes clinical outcomes and quality of life”⁸⁴.

Sackett and colleagues explicitly note that evidence-based practice is not a static state of knowledge but rather represents a constantly evolving state of information. Healthcare practitioners have the obligation to continually stay abreast of clinical developments in research and to incorporate such developments into daily care ^{84,269}. To practice EBM the following steps must be followed ⁸⁴:

- Convert one's need for information into an answerable question.
- Track down the best clinical evidence to answer that question.
- Critically appraise the evidence in terms of its validity, clinical significance, and usefulness.
- Integrate this critical appraisal of research evidence with one's clinical expertise and the patient's values and circumstances.
- Evaluate one's effectiveness and efficacy in undertaking the four previous steps, and strive for self-improvement.

Evidence-based practice offers healthcare providers both the opportunity and the challenge to “avail themselves of the emerging knowledge-base and of the developing philosophy and approach to service delivery known as evidence-based practice”, which is “scientifically tenable and ethically incumbent” ²⁶⁹. Evidence-based practice presents significant complexities and opportunities not only for those in academics in charge of developing and maintaining the state-of-the-science, and the state-of-the-art clinical training programs, but also to those providing clinical supervision to physicians and other healthcare providers ²⁶⁹.

2.1.2. Knowledge Translation

In 2000, the term knowledge translation was defined by the Canadian Institute of Health Research ²⁷⁰ as “the exchange, synthesis and ethically-sound application of knowledge— within a complex system of interactions among researchers and users—to accelerate the capture of the benefits of research for Canadians through improved health, more effective services and products, and a strengthened health care system”²⁷¹. The World Health Organization (WHO) defined knowledge translation as “ the synthesis, exchange, and application of knowledge by relevant stakeholders to accelerate the benefits of global and local innovation in strengthening health systems and improving people’s health” ²⁷². In other words, “any activity or process that facilitates the transfer of high-quality evidence from research into effective changes in health policy, clinical practice, or products ²⁷³”. The Canadian Institute of Health Research ²⁷⁴ has defined the steps for knowledge translation, to include: dissemination, communication, technology transfer, ethical context, knowledge management, knowledge utilization, two-way exchange between researches and those who apply knowledge, implementation research, technology assessment, synthesis of results with the global context, and development of consensus guidelines. The steps encompass elements previously implicated in the application of knowledge²⁷⁰. Sudsawad characterizes knowledge transfer as:

- Including all steps between the creation of new knowledge and its application,
- Needing multidirectional communications,
- An interactive process,
- Requiring ongoing collaboration among relevant parties,
- Including multiple activities,
- A nonlinear process.

- Emphasizing the use of research-generated knowledge that may be used in conjunction with other types of knowledge,
- Involving diverse knowledge-user groups,
- User and context specific,
- Impact oriented,
- An interdisciplinary process.
- Knowledge translation has been increasingly valued in healthcare as it “represents the process of moving what is learned in research to actual application of such knowledge in variety of practice setting and circumstances”²⁷⁰.

2.1.3. Translation of Knowledge in Evidence-Based Practice

The growing interest in evidence-based practice which integrates research evidence into clinical decision-making coincides with an increased emphasis on knowledge translation^{74,270}. Evidence-based practice makes knowledge translation an increasingly imperative discipline²⁷³. It aims to “conceptually combine elements of research, education, quality improvement, and electronic systems development to create a seamless linkage between interventions that improve patient care and their routine implementation in daily clinical practice²⁷³”. Despite the strong endorsement for evidence-based practice, the translation of research findings (knowledge) to clinical practice is a well-recognized challenge in healthcare^{270,275-279}. Common hurdles include: the sheer volume of research evidence; time required to gather findings; skills needed to interpret research evidence; conflicting evidence, irrelevant evidence; limited access and cost of continuing education; lack of supervisory support; lack of or limited access to scholarly articles; physician attitudes towards evidence-based practice; inadequate organizational leadership;

inadequate responsiveness to program participants; failure to include stakeholders from multiple disciplines; lack of transparency to foster trust; and difficulty in evaluation of efficacy of final program on patient health ^{96,99,262,279-282}. As a result of the challenges associated with the translation of knowledge into practice, gaps exist between research and clinical practice, which present a real barrier to clinical implementation of innovative research findings ²⁸³. The consistent failure to translate evidence into practice, has contributed to three major shortcomings in healthcare system ²⁸⁰ which include: preventing patients from benefiting from latest discoveries and advances in treatments and interventions; exposing patients to unnecessary risks of iatrogenic harms; and exposing healthcare systems to unnecessary expenditures at significant cost ²⁸⁰. Both the knowledge and the application of the knowledge are essential in all areas of medical practice. It is imperative to bridge the gap that exists between research evidence and practice.

2.1.4. Technology in Healthcare

Technology is the engine of change that has set the stage for an unprecedented transformation in healthcare ²⁸⁴. Digitization of data has been one of the key underlying factors in the rapid transformation of healthcare as and in other industries. Digitization refers to the conversion of an analog signal to a digital one ²⁸⁵, where analog data are measured as continuous variables and digital data are measured as simple discrete variables ^{285,286}. Digitization of patient care has been driven by wireless sensors and devices, imaging, health information systems, and genomics ²⁸⁷. Each of the digital medical technologies is propelling healthcare forward at an unprecedented pace, focusing on human biology, physiology, and anatomy to illuminate what Topol refers to as the “high definition man”²⁸⁷. Use of technology in healthcare has been focused on digitization of

various processes, which has led to the accumulation of large amount of diverse and siloed electronic data related to admissions, billing, health records, finances, imaging scans, pharmacy, lab, transfusion service, insurance claims, scheduling, and etc., in disparate health information systems. Various reform efforts like the ACA's meaningful use requirement, accountable care organizations, health information exchanges, public health exchanges, and other initiatives seek to place patients at the center of care ²⁸⁸ with the use of various technologies. The aim of the healthcare initiatives is to improve patient care and lower the cost through meaningful use of patient data and information in order to enhance appropriate decision-making and interventions. "Health information systems serve as an indispensable foundation for improved delivery of routine health services in an evidence-based manner"²⁸⁹. Development of information systems has provided a way to reduce medical errors, improve patient outcomes, and increase collaboration among care providers ²⁹⁰. Although these approaches have the potential to dramatically improve the delivery and quality of healthcare, they are contingent upon data exchanges and interoperability of the various information systems which to date have been a great hurdle and "largely an unreach goal ²⁹⁰".

2.1.5. Uniqueness of Healthcare Data and Complexity of Reporting

Healthcare data are unique both in complexity and diversity. Healthcare data have characteristics that vary from any other industry. In a healthcare setting data reside in multiple source systems (i.e. from EHRs, medical credentialing systems, claims processing systems to specific department systems such as lab, transfusion service, pharmacy, radiology, etc.). Data also occur in different formats (e.g. text, numeric, paper, digital, pictures, video, multimedia, etc.). It is the norm for the data to exist in different systems and in different formats ²⁹¹. For example, in the

case of a patient with a broken arm, the medical records show an image of a broken arm. However, the broken arm appears as ICD-9 code 813.8 in claims data. Additionally, contrary to common belief, data have been anything but consistent. For years, clinical data have been captured on paper in however way is most convenient for the healthcare provider with little regard for how the data could eventually be aggregated and analyzed ²⁹¹. EMR and EHR systems have attempted to standardize the data capture process, but physicians and other healthcare providers have been reluctant to adapt to a “one-size-fits-all” approach. As a result, most of the data have been captured in both a structured and an unstructured manner, which makes it difficult to aggregate and analyze ²⁹¹. Another problem has been the variability and inconsistencies of healthcare data. Variability exists in the length of the same data element (e.g. patient last name 50, 25, 16 characters), and in the values for the same elements (e.g. Gender: M, F, or U; or Male, Female, or Other). Inconsistencies exist in naming conventions (e.g. Date of Admission, Admission Date, Admit Date, etc.), and in definitions of terms (e.g. patient access modules defined date of admission as the date inpatient or day surgery visit occurs; trauma registry defined the date on which the trauma patient enters the operating room, and etc.) ²⁹². Addressing the complexity surrounding the development of standard processes to improve quality is one of the main goals of recent changes in healthcare system. However, aggregation of administrative data (e.g. admissions, insurance, billing) with clinical data (e.g. EHR, pharmacy, radiology, transfusion service, lab) to create a more complete picture of the patient’s story is very challenging. There is no finite number of identical parts to create identical outcomes. Rather there is an amalgam of individual systems each with its own complexity designed to capture different information about an individual. Managing data from disparate systems and turning them into meaningful information requires a sophisticated set of tools, approaches, and a broad

range of expertise ²⁹¹. As research advances and knowledge is enriched, new best practices arise with new definitions of terms, new criteria, and different approaches. Best practice is continuously being redefined in an unpredictable manner contributing to the complexity of aggregating contextual data. Furthermore, as medicine and healthcare technology evolve, regulatory and reporting requirements change (i.e. CMS quality requirements such as readmissions) adding to the burden of aggregating and reporting of data.

2.1.6. Diverse Health Information Systems

Integration and interoperability of different health information systems is a fundamental requirement for achieving continuity of care and a comprehensive view of patients' health. Currently, health information systems used in each department (i.e. admissions, billing, laboratory, pharmacy, transfusion service, etc.) within hospitals and across healthcare organizations have been developed independently with diverse sets of approaches in methods, processes, and procedures for capturing data and presenting the information ²⁹³. Additionally, lack of specificity in healthcare standards and information sharing protocols, has resulted in a "large number of heterogeneous and distributed proprietary models for recording and representing patients' data and information"²⁹⁰. Diverse and disparate health information systems pose great challenges for the exchange of patient data causing duplication of data, a considerable amount of transcription (i.e. transfer of data from one system to another such as transfer of patient diagnosis data from patient records to an order entry form) and maintenance of referential integrity when data is replicated or duplicated ²⁹³. Other challenges include the cost of uncontrolled redundancy, maintenance, and updating. Much of the difficulty pertains to the

proprietary nature of each system and the syntactic and semantic differences across them. These challenges are “exacerbated by the lack of standardization between health information systems and the costs associated with software upgrades and data restructuring” ²⁹⁴. As a result of the disparity that exists among health information systems, gaining user acceptance is another major challenge due to the learning curves associated with the use of each system resulting from different user interfaces, overlapping features, separate user identification procedures, and many more issues.

2.1.7. Data Integration Challenges

“A key attribute of a learning health care system is the ability to collect and analyze routinely collected clinical data in order to quickly generate new clinical evidence, and to monitor the quality of the care provided. To achieve this vision, clinical data must be easy to extract and stored in computer readable formats” ²⁹⁵. Clinical data provide the health context directly related to an individual patient. Clinical data include patient vital signs, laboratory tests, scans, medical history, immunization record, family history, life-style information, physical exams, diagnoses, progress notes, operative reports, ambulatory care reports, care plans, medication reports, and etc. Integration of clinical data “facilitates the coordination of patient care across conditions, providers, settings, and time in order to achieve care that is safe, timely, effective, efficient, equitable, and patient-focused” ²⁹⁶. Integrated data can greatly assist care providers in making accurate assessments and interventions, administering proper treatments, and optimizing operations among peers in the department and across organizations. However, achieving clinical integration faces significant challenges due to heterogeneity of healthcare ecosystems in which:

data tend to reside in multiple different sources; data collection occurs in different formats (i.e. text, numeric, hand written paper, digital, pictures, videos, and etc.), and the same data exists in different formats in multiple systems. Structured and unstructured data is another issue²⁹⁷. EHR systems attempt to standardize the data capture process. However, providers are disinclined to adapt to a one-size-fits-all approach to documentation and unstructured data capture has been put in place to allow autonomy and leniency in this process²⁹⁰. This approach introduces inconsistency in data capture and makes data aggregation and analysis very cumbersome. Complexity of medical data is another factor. Although construction of workflows and standardized processes for data capture does improve quality, the number of variables that exist in medicine makes the effort far more challenging, particularly when the variables are being captured in disparate applications²⁹¹ and are subject to change as new evidence emerges. The variability that exists in healthcare terminology and definition is also problematic²⁹⁰. Much of the data are not available in easily extractable and structured formats. While textual and unstructured data are convenient for both entering and reviewing of patient history and progress by care providers, they present significant obstacles for graphic presentation, searching, summarization, and statistical analysis²⁹⁵.

“The principles of evidence-based health care posit that clinical and public health decisions should be made using, among other elements, the best available clinical evidence”^{75,295,298}. Evidence-based practice focuses on incorporation of the latest scientific and clinical evidence into practice⁷⁵. It is gaining ground in the current healthcare environment as a means to improve quality and productivity of healthcare services by reducing variation in care⁷⁵. As great as evidence-based practice is, it also contributes to the challenges of data integration. The

continuous advancement in the understanding of the functions of the human body, adds new variables, changes what is considered important, adds new variables, changes the how, what and when of measurements, and alters how to determine goals and reach targets. As a result of our advanced understanding we routinely add inconsistencies to ways we aggregate and manage data. Changing and increasing regulatory and reporting requirements also affect data integration. The Center for Medicare and Medicaid Services requires various types of reports such as clinical quality measures, outcome based measures, readmission rate, and etc. to provide transparency in quality and pricing information to public ²⁹¹.

2.1.8. Issues of Interoperability

It is widely accepted that medicine requires complex and highly specialized information technology systems ²⁹⁹. This complexity has led to the development and use of a variety of diverse health information systems that often address the needs of small units within a larger organization. The concept of seamless interoperability rests at the center of all this. “Interoperability is a fundamental requirement for ensuring that widespread EMR adoption will give us the social and economic benefits that we want”³⁰⁰. There are three dimensions to interoperability, which include:

- Business Interoperability focuses on organizational context such as policies, agreed upon organizational communication practices. Business Interoperability is independent of existing technologies.
- Technical Interoperability tolerates heterogeneity in hardware and software but allows them to coexist in harmony, in addition to “Plug-and-play” of new devices.

- Information Interoperability focuses on the ability to interchange data in a meaningful manner through establishment of common semantics ³⁰¹.

An interoperable healthcare technology system facilitates the “right information at the right time and place” and depends on “systems being able to exchange information in a way that is safe, secure, and reliable” ³⁰². The concept of interoperability is multifaceted and means something different for different individuals. HIMSS Dictionary of Health Information Technology Terms, Acronyms, and Organizations lists seventeen different definitions from purely technical to definitions that include all the various aspects of interoperability such as technical, social, political, and organizational. A widely used definition has defined interoperability as the “ability of two or more systems or components to exchange information and to use the information that has been exchanged”³⁰³. There are three main components to this definition: (i) the exchange of information (technical interpretability), (ii) the ability of recipient to use that information (semantic interoperability), and (iii) the actual use of the information (process interoperability). Each of the three types carries a same weight as the other two. Because of the interdependency among them, all the dimensions must be present to deliver significant business benefits³⁰⁴.

Although significant funds have been allocated to address problems of interoperability, the efforts have been largely unsuccessful ²⁹³. Interoperability is beneficial, but certainly not easy to achieve. This is because patient health records contain an extensive set of diverse data and information types, ranging from family history, social habits, diagnostic tests, clinician assessments, medical history, care interventions and treatment plans. As hospitals introduce new workflows and technology capabilities to support increasing numbers of clinical quality measures, they face numerous challenges around discrete data capture, data quality and

standardization, including accuracy, integrity, searchability, completeness, quality, redundancy and consistency, and misaligned, or non-existent incentives^{305,306}.

Some of the high-level barriers that slow down attempts to achieve interoperability include:

- Limited syntactic interoperability, different systems represent the same data in different ways³⁰⁷;
- Limited ability to capture clinical notes, discharge summaries, administrative information, etc. in an structured format³⁰⁸;
- Poor quality of data, which includes redundancy, duplication and incompleteness of data, as well as multiple listings of the same data. Poor data quality hinders analyses and creates lack of trust in users. In addition, correcting for poor quality data is both time- and resource-intensive undertake, which puts further pressure on already strained healthcare intuitions³⁰⁹;
- Difficulty in employment of standards in health information technology. There is a significant need for consensus in the use of standards in the healthcare industry. Types of standards include:
 - Standards for data exchange and messaging (to allow transactions to flow consistently between systems or organization using instructions for structure, format, and data elements);
 - Clinical terminology standards (use of ontologies to provide specific codes for clinical concepts);
 - Document standards (define for every documents what information must be included and where they must be found);

- Conceptual standards (allow data to be transported from one system to another without losing meaning or context);
- Application standards (the manner in which business rules are implemented and various software systems interact);
- Architecture standards (to define processes in data storage and distributions).

Although, there have been various initiatives and efforts to develop standards, there has been a lack of effort and buy-in for deployment and effective use of those standards³¹⁰. The issue of standards on its own greatly hinders attempts for interoperability.

Other factors hamper interoperability efforts including:

- Lack of cooperation between health information system vendors, as vendors may feel siloed solutions are more beneficial to their bottom line ³¹¹. Vendors have not been incentivized to enable sharing of health information across vendor boundaries. As an example, EHR vendors have been focused on promotion of information sharing only through their monolithic systems as opposed to supporting interoperability standards ³⁰⁶.
- Failure among providers and across organizations to share their data with each other, or share the connection burden and costs ³¹².
- Vendor resistance to initiatives, as the experts question the effectiveness of meaningful use incentives in spurring efforts to achieve interoperability. This has led to speculation that EHR and other solution vendors are purposefully stalling because it is not in their best interest to achieve interoperability yet ³¹¹. Such speculation bolsters the idea that interoperability is not just a technical issue, but also a political, economic and even social one.

Other complexities of interoperability pertain to the dynamic nature of patient health records, the rapid accumulation of patient data, and the limited or lack of availability of information in a meaningful manner at the critical point of care for decision making.

The Affordable Care Act's meaningful use incentives are still in the "carrot" phase, which encourages and simultaneously forces health care organizations to potentially over-commit and invest multi-million dollars on the implementation of a single EHR system to achieve the mandated criteria, with the knowledge that interoperability remains a chief concern³¹³. As a result of the lack of interoperability, widespread adoption of EHR systems has exacerbated the problems of information silos and the fragmentation of patient data and care delivery which exist today. The "stick" phase begins after 2015 and will affect healthcare organizations if they are unable to generate and report complete patient quality measure outcomes, due to the heterogeneity of the healthcare environment, disparate health information systems, and fragmented patient data. This will potentially result in a significant financial impact³¹³ for healthcare institutions. The push for healthcare organizations, hospitals, clinics, and physicians to collaborate more closely to form accountable care organizations may have unintentionally created an atmosphere for slowing down cross-vendor interoperability efforts, as vendors use these initiatives to further strengthen their sales pitch and push healthcare organization to buy-in to monolithic systems³¹³. Until healthcare reform initiatives properly incentivize vendors, healthcare institutions, and providers, and until vendors and providers are willing to extend their boundaries and share the responsibility of interoperability, health information exchange will likely continue to progress slowly and will negatively impact continuity of care, quality of patient care, and cost of healthcare³¹³. These unintended consequences have potentially slowed

down interoperability efforts. Without a complete and seamless interoperable environment, the great promise of seamless patient health records will not be achieved.

2.1.9. Healthcare Silos

“Healthcare is not a system but a set of independent actions and activities that often have little or no continuity. One reason for this lack of continuity is the silos that exist within the healthcare environment”³¹⁴. The information silos are part of organizational culture and a way of thinking. In a siloed organizational structure, departments generally do not share the same priorities, goals, and even the same tools and information technology solutions ³¹⁵. Each department operates as an individual unit or entity within a healthcare enterprise, with different priorities, responsibilities and vision ³¹⁶. For many years this model worked well, as there was limited need to communicate with other departments, with healthcare providers within the hospital, or across healthcare institutions ³¹⁶. As a result of siloed organizational structures, information gathering, processing, communication, and management have also been operating in an insular manner ³¹⁷. Although health information systems have been essential to health care delivery, they have been incapable of reciprocal operations with other related information systems ³¹⁷. As a result of this culture, “the health care sector as a whole has historically trailed far behind most other industries in investments in information and communications technologies” ^{317,318}. Most healthcare related information technologies and communication investments have been concentrated on the administrative and business side of the healthcare, rather than on the clinical side. Until recently because of this “prolonged under-investment, little overall progress has been made toward meeting the information needs of patients, providers, hospitals, clinics, and the broad regulatory,

financial, and research environment in which they operate”³¹⁷. Healthcare systems are comprised of a variety of databases that have been designed and built separately for different applications with no common data model constructs. This makes communications across databases very cumbersome. “Communication between people using databases is not the same as communication among people, which is adequately handled by natural language and mathematics. Nor is it the same as communication between people and computers which is adequately handled by computer programming language. Communication across databases requires a very different type of language, one that addresses data meaning using functional data classification and a finite number of relations. Without the use of a data language, comprehensive person to person communication via databases is extremely limited and true system integration is virtually impossible”³¹⁹. Organizational structures, disparate health information systems, data integration barriers, and lack of or limited health information systems interoperability create silos at many different levels within and across healthcare institutions resulting in fragmented care delivery systems.

2.1.10. Central Role of Analytics in Healthcare

Data analytics and continuous audits are not new concepts. Their appeal and vitality are on the rise in the healthcare industry as it transitions from volume-based business to a value-based business. “With increasing demands from consumers for enhanced healthcare quality and increased value, healthcare providers and payers are under pressure to deliver better outcomes”⁶⁷. Clinical and healthcare organizational data have a vast potential and broad range of uses, from service line profitability, patient quality of care, and outcome analysis, to claims and revenue

cycle management and utilization. Building analytics competencies can help organizations harness “big data” providing critical insights in order to make assessments, meet organizational goals and achieve competitive advantage ³²⁰. Analytics will be central in demonstrating value and achieving better outcomes by using new treatments and technologies, and refining outdated practices. Analytics can improve effectiveness and efficiency in numerous ways by managing small details as well as large processes, aiding in exploration and discovery, helping policy and program design and planning, improving healthcare service delivery and operations, enhancing sustainability, mitigating risk; and providing a means for measuring and evaluating critical organizational data ⁶⁷. Healthcare organizations increasingly use analytics to consume, unlock and apply new insights gained from their information.

According to a survey report by HIMSS³²¹, healthcare organizations choose to report on the following types of information:

- Data that they are required to track by the government or other external organizations
- Data that has the potential to significantly reduce costs and enhance their ability to reduce the inventory of high-cost products;
- Information that is required for recertification of professional staff.

Although healthcare institutions reside in a rich data environment, the healthcare industry lags far behind in analytical capabilities because of the diversity and disparity among health information systems and the challenges associated with interoperability and integration of the various systems, lack and/or limited use of standards, and the use of different data types, data models, and information. Performing analytics on data that is collected and aggregated using a single health information system may not be as cumbersome. The difficulty comes with analytics

that aim to examine heterogeneous data from multiple diverse source systems. This type of analytics requires aggregation of patient data from multiple health information systems, data such as admission and discharge records, patients' vitals, laboratory tests, patient medical history, immunizations, family history, life style, physical exams, diagnoses, progress notes, operative reports, ambulatory care, care plan, medication report, etc. in conjunction with administrative data.

A 2010 report by Healthcare Information and Management Systems Society (HIMSS) has identified a number of barriers and challenges that impact efforts to effectively perform analytics on clinical and administrative data across multiple source systems and data warehouses³²². The following issues are in addition to interoperability and integration challenges indicated in previous sections and they include³²²:

- Static reporting of data and information, which is mostly done in a paper format. These types of reports do not allow the recipient to manipulate data and the information. Analysis of paper reports requires extensive data re-entry for manipulation purposes in order to yield a satisfactory layout.
- The assumption that electronically housed data is analysis ready. Data storage, transformation, and governance are required prior to any analysis.
- Limited or lack of access to data elements that are required for analysis. These types of data elements may be captured in an alternate format that is not streamlined into the main data collection tool (e.g. lab values captured at a different site), which requires data to be either entered manually or omitted from the overall analysis.

- Unstructured or free-form of data capture. These types of data require human curation and conversion to a discrete or structured field, in order to be used for analysis.
- Required expertise. Apple-to-apple results that include many different variables are challenging and requires skills and expertise to understand what is being measured and why. Additionally, it is also important to understand the clinical context of a particular data point, and how the different clinical scenarios can impact that data point. There are also issues with nomenclature, and ensuring that data is captured using the same terminology (e.g. data normalization and semantic interoperability).
- Limited and/or lack of skilled personal with combination of technical, statistical, and clinical background to analyze the data that is required for evaluation. There are further constraints not only because healthcare organizations lack the financial resources to hire additional personnel, but also because it can be difficult to find individuals who possess the right skills for the job. As a result, some organizations are turning to external resources to meet these needs³²¹. Many healthcare institutions rely on different technological solutions to meet their analytics need with dependence on limited information technology resources and solutions vendors to develop reports and tools in order to effectively analyze clinical data. Others are turning to niche vendors that specialize in the development of data warehouses or data mining to assist in different types of analysis ³²¹. To date, the majority of the specialized reports are in a form of managed static reports, which prevent the end user from manipulating the information for better understanding or further analysis ⁶⁷. Every question or a small change to the reports requires involvement of technical personal and waiting for extended periods of time.

2.1.11. Current Use and Challenges of Clinical Analytics

A research report by the MIT Sloan Management Review, in partnership with the IBM Institute for Business Value defined three specific analytics capability segments among healthcare organizations including: aspirational, experienced, and transformed ³²³. Each of the three segments has its own set of challenges and opportunities:

- Aspirational: “These organizations are the farthest from achieving their desired analytical goals. Often they are focusing on efficiency or automation of existing processes, and searching for ways to cut costs. Aspirational organizations currently have few of the necessary building blocks – people, processes or tools – to collect, understand, incorporate or act on analytic insights ³²³”.
- Experienced: “Having gained some analytic experience – often through successes with efficiencies at the Aspirational phase – these organizations are looking to go beyond cost management. Experienced organizations are developing better ways to effectively collect incorporate and act on analytics so they can begin to optimize their organizations ³²³”.
- Transformed: “These organizations have substantial experience using analytics across a broad range of functions. They use analytics as a competitive differentiator and are already adept at organizing people, processes and tools to optimize and differentiate. Transformed organizations are less focused on cutting costs than aspirational and experienced organizations, possibly having already automated their operations through effective use of insights. They are most focused on driving customer profitability and making targeted investments in niche analytics as they keep pushing the organizational envelope “ ³²³.

On the analytics sophistication spectrum, the study showed 35 percent of 116 healthcare organizations in the United States are in the aspirational segment (with the following characteristics: new or limited users of analytics, focused on analytics at point-of-need, and turn to analytics for ways to cut costs), 45 percent are in the experienced segment (established users of analytics, seek to grow revenue with focus on cost efficiencies, and seek to expand ability share information and insights), and only 16 percent are in the transformed segment (use of analytics is the cultural norm, highest levels of analytics prowess and experience, seek to target revenue growth, and feel the most pressure to do more with analytics) ³²³. The future demands that healthcare organizations focus on the biggest and highest value opportunities and within each opportunity, to start with questions, not data, and embed insights to drive actions and deliver value, and keeping existing capabilities while adding new ones ^{67,323}.

2.1.12. Physician Performance Measure and Reporting

In 2001, a report by the Institute of Medicine encouraged healthcare organizations and purchasers to implement policies to increase the likelihood for delivery of “safe, effective, patient-centered, timely, efficient, and equitable” care ³²⁴. In 2010, the enactment of ACA has changed the practice of the healthcare industry from volume-based to value-based healthcare delivery, and with it changed the physician reimbursement model³²⁵. The recent changes are transforming the context in which physicians and other healthcare providers deliver care ¹⁰⁴. “A key strategy on the policy agenda is advancing performance measurement at all levels of the healthcare system, and in particular, at the physician level where there is substantial unexplained variation in practice that leads to poor quality, inefficient delivery of care, and wasteful spending on care. Physician performance measurement, including both quality and cost-efficiency, is an

important vehicle stimulating improvements in quality and costs of delivering care”³²⁶. In order to move the physician measurement and reporting initiative forward, continued development of evidence-based quality assessment measures must be developed in a broader and deeper array of clinical conditions, medical specialties and medical procedures. Efforts are underway nationally, by CMS, as well as regionally by many private payers to develop reporting and payment systems that support and reward quality and the efficient delivery of care³²⁶. Measurement of physician quality performance has become increasingly important for health plans as the basis for quality improvement, network design, and financial incentives^{327,328}.

2.1.13. Need for Data Integration and Analytics to Assess Physician Performance

The shift to reimbursement based on performance is spurring new ways to assess physician practices and performance. The shift requires use of data analytics capabilities to generate meaningful insights about physician performance. Analytics capabilities provide a feedback mechanism to evaluate changes in practice and to provide a deeper understanding of physicians’ decisions through quantification and assessment of trends. Reporting on compliance to best-practice guidelines and high level metrics alone is insufficient. An analytics framework is essential in evaluating changes directly impacted by various initiatives (i.e. best-practice guidelines, education, incentives, etc.), identifying new areas for improvement, and avoiding unintended consequences and outcomes.

A key component of analytics capability is data integration, which is the capture, cleansing, storage, and linkage of data from clinical and financial sources³²⁹. A complete data integration

solution encompasses discovery, cleansing, monitoring, transforming, and delivery of data from variety of sources³³⁰. Data integration is the combination of technical and business processes used to combine data from disparate sources into meaningful and valuable information³³⁰. There are significant barriers to achieving data integration and conducting analytics on quality improvement and patient outcomes. Some of the barriers are:

- The variation that exists in the study of clinical data. There is variation depending on the complexity of the protocol, the design of an individual study and the method of data collection. This prevents standardization of approaches to data integration from multiple disparate source systems.
- Difficulty in meaningful integration of clinical data because of the variance of semantics for different contexts.
- Lack of standardization and the unstructured nature of the significant portion of clinical data which necessitate complex transformations at different phases. This poses a hurdle for auditability of data for regulatory and compliance purposes.
- Interfacing disparate systems requires extensive integration exercises that turn into large projects and require significant resources.
- Diverse systems are used at different phases of clinical data life-cycles because individual systems are usually put in place to fulfill a specific business need^{296,305,331-333}. Individual systems are combinations of home grown and commercial products from multiple vendors, which significantly adds to the complexity of the integration process.

A 2013 report by the Health Initiative and the College of Healthcare Information Management Executives focused on the state of health analytics in the area of improving quality and lowering cost. The survey group included 102 organizations and was comprised of hospitals (37%),

integrated delivery networks (33%), academic medical centers (13%), and others (11%). The study examined attitudes toward data use, trends in business use cases for data and analytics, technological solutions employed by organizations, and associated challenges and barriers ³³⁴. “Respondents’ attitudes toward data and analytics reflect a common understanding of the potential impact and benefits of using data and analytics to help drive organizational decision-making and action. A large majority (82%) indicated that bi-directional sharing of clinical and/or patient data with local healthcare organizations is important or very important to their organization. It is likely that increased pressure to meet data sharing requirements under the federal EHR Incentive Program has contributed to this belief. Additionally, nearly 80 percent of respondents felt that leveraging big data and predictive analytics is important to their organization’s strategic plans and priorities. However, the reality on the ground may not match the desires of respondents. Eighty-four percent believe that the application of big data and predictive analytics is a significant challenge for their organization”³³⁴ due to “uniqueness and complexity of healthcare data” ³³⁵. “Only 45 percent of respondents feel that their organization has implemented a flexible and scalable plan to adapt to the growing volume, liquidity, and availability of electronic health data”³³⁴.

The report ^{334,336} highlighted some of the key analytics applications that were reported by the participants, which included:

- Revenue Cycle Management which focuses on cost reduction. Healthcare institutions are closely managing and monitoring their revenue cycle to ensure profitability. Analytics have been utilized to determine patient eligibility, validate coverage, authorize services, assess payment risk, manage submissions, and track performance.

- Resource Utilization which focuses on ways to concurrently improve patient outcomes and reduce costs using finite resources. Analytics have been used to track and manage workforce, patient volumes, services, and supply chain.
- Prevention of Fraud and Abuse which accounts for between 3 and 15 percent of annual healthcare expenditures. “Fraud refers to a calculated misrepresentation of facts aimed at convincing payers to process a false claim for financial gain. Similarly, abuse refers to neglect of accepted business or medical practices resulting in higher reimbursements. While fraud is a willful act, abuse is unintentional. Common forms of fraud and abuse include improper coding, billing for services not actually provided, and providing unnecessary medical services given the patient’s condition”^{334,337}. Analyses of billing and claims data assist in identification of “fraud and abuse by predicting expected service utilization and comparing it to actual billing information. Trends and patterns in claims data can help organizations create a baseline for behaviors indicative of fraud and abuse and further investigate as necessary”³³⁴.

Population Health Management which is one of the important components of new healthcare initiatives and the basis for new healthcare delivery models (i.e. ACOs) focused on improving outcome for the entire population, rather one individual seeking help. It requires “organizations to define a population, identify gaps in care, stratify risks, engage patients, manage care, and measure outcomes”^{334,338}. Analytics plays a significant role “given the vast amount of important health-related data to consider when caring for an entire population. Data analysis can assist healthcare organizations in recognizing populations consuming the most resources or at greatest risk for hospital readmissions, enabling them to target high-risk groups to reduce costs and

improve outcomes. Analytics can also help identify trends in disease prevalence, determine the comparative effectiveness of treatment options, and derive best practices”³³⁴.

Quality Improvement which focuses on “broad categories of variations in services, underuse of services, overuse of services, misuse of services, and disparities in quality”^{334,339}. Analytics facilitates quality improvement efforts such as utilization and outcome analyses, patient adverse outcome reports. Quality improvement has been identified by 88 percent of respondent³³⁴ as a key area of focus.

The key analytics applications reported by the survey highlight the gap that exists in the ability to perform analytics on different types of data from disparate health information systems. The analytics functions represented in the survey do not require data from various health information systems. The reported applications of analytics are mostly focused on extracting data from either one or two systems. Revenue Cycle Management, Prevention of Fraud and Abuse, and Population Health Management mostly use claims data. Claims data in the healthcare industry is known for their cleanliness and completeness. These strengths perfectly counter the limitations of clinical data. Some of the characteristics of claims data include: use of diagnosis and procedure codes that are standardized nationwide (i.e. ICD-9 and ICD-10 in October 2014); incorporation of multiple security levels into coding and claims processes; and automation of data cleansing to ensure accuracy. In addition, since healthcare institutions’ workforce has a stake in successful submission of claims, everyone goes to great lengths to continually improve accuracy and comprehensiveness of claims before submission. Other robust characteristics of claims data is in its shareability, partly due to its structured and standardized format, and partly

because of the powerful incentive behind efficient transmission and exchange of the information. After all, this is how providers are paid ³⁴⁰.

Data integration and analytics challenges are not unique to healthcare and have been encountered in other industries. The difference is that the healthcare industry operates in a more heterogeneous data ecosystem with different levels of regulations, standardization, and clinical intricacy that add to the complexity of matter. Healthcare institutions are tasked to gain greater performance and operational efficiencies to unify fragmented clinical processes, quality performance, people, projects, and siloed systems in order to drive evidence-based decision making. Meanwhile, healthcare payers are demanding evidence of efficacy of treatments before authorization of payments. Data and availability of information on the efficacy of various interventions is at the heart of evidence-based decision making, and quality of patient outcomes.

2.1.14. Performance Management System

Performance measures have been described as “quantifying the efficiency and effectiveness of past actions” ³⁴¹. The process involves “regular collection of data to assess whether the correct processes are being performed and desired results are being achieved” ³⁴². Performance measures are a significant part of any organizational strategy, planning, and reporting. They can assist healthcare institution executives and heads of hospital departments in reviewing trends in various areas, making decisions on how to improve departments based on a broader scope, and refining organizational performance. There are many reasons why any healthcare institution must

measure performance including: quality improvement, transparency, accreditation and participation in financial incentive programs.

Performance Management System (PMS) encompasses multiple components; measure, metric, indicator, and key performance indicators. In many organizations, these separate phrases are used interchangeably, and/or are merged into a single concept. It is important to highlight the fact that each component represents a different notion.

- Measurement is defined as the act or a process of measuring; a figure, extent, or amount obtained by measuring³⁴³. A result of measuring would be a figure expressing the extent or value that was obtained by measuring against a standard. An example of a measurement may be “10 centimeters”, the centimeter is the standard, and 10 identify how many multiples or fractions of the standard are being appraised.
- Metric is a quantitative measure of the degree to which a system, component, or process possesses a given attribute³⁴⁴. Metric is a calculated or composite indicator based on two or more measures. It presents a trend. As an example recording hourly body temperature provides a trend on whether the temperature is remaining constant, increasing, or decreasing. Metric is a comparison of two or more measures.
- Indicator is an entity that provides insight on process improvement activities concerning goal attainments. An example is body temperature of 99.1 degrees Fahrenheit as compared to normal body temperature of 98.6 degree Fahrenheit. Indicator is a device or variable that can be set to a prescribed state based on the results of a process or the occurrence of a specified condition³⁴⁴. An indicator generally compares a metric with a baseline or expected result.

- Key performance indicators are indicators that are very specific. They are measureable values that demonstrate the effectiveness of a process that is contributing to the attainment of a single organizational key objective. Performance measures are used in a type of analytical approach that provides information about key aspects of activities, e.g. in transfusion medicine, the appropriateness of transfusion. They drive the results of the key activities in an evidence-based program. Analytical processes must be applied to the measures. Clinical analytics can be classified into two categories of retrospective (looking back) and prospective (looking forward) measures. “Performance measures are typically considered retrospective analyses; it requires aggregation and analysis of data and information on a performed task over an extended period of time”³⁴⁵. Performance measures are categorized based on whether they analyze an input or an output of a care process. Types of performance measures include ³⁴⁵:

- Resource and Efficiency Measures: track specific resources used, such as red blood cell, platelet, plasma etc.
- Process Measures: track the level of compliance with specific guideline or standards, for example order of red blood cell transfusion based on a pre-transfusion lab value (i.e. hemoglobin level).
- Structural Measures: track information about how a care delivery system operates for example number of transfusions performed by a physician.
- Outcome Measures: track the impact of a particular intervention, such as transfusion on patient’s health (e.g. review of patient days – “a unit in the system of accounting used by healthcare facilities and healthcare planners. Each day represents a unit of time during which the services of the institution or facility are

used by a patient ³⁴⁶; meaning 100 patients in a hospital for 1 day would be represented as 100 patient days.

- Patient Experience Measures: are based on surveys conducted from patients to track perception and satisfaction for the level of care received.

Characteristics of a robust PMS include: strategic support; holistic view of progress through quantitative and qualitative perspectives; incorporation of the needs and activities of decision-makers; mechanism for routine and timely reports on progress; detailed attention to accuracy of data; calculation of measure in reporting the information; and consistency and feasibility in visual presentation of information back to stakeholders³⁴⁷. To implement an evidence-based PMS, identification of metrics, indicators, and key performance indicators is required in order to qualitatively or quantitatively measure the past, and conduct historical analysis to forecast potential future outcomes ³⁴⁸. The various measures can portray a snapshot of pre-defined standards established according to the evidence. Through utilization of the PMS, the success of a project, program, department, or an organization can be defined and evaluated. Metrics provide a way for trend analyses. Key performance indicators provide actionable metrics that can be used to increase the effectiveness and efficiency of operations ³⁴⁸, directly associating organizational strategic plans with performance. Key performance indicators differ from other measures. They are very specific measures that highlight aspects of performance that directly tie strategic objectives to operational routine (i.e. physicians practice). Therefore, they are integral in providing insights on the level of performance and progress and in determining whether improvements are necessary.

2.2. Application of New Strategies to Transfusion Medicine Practice

Human error is a nearly constant component of human involvement in any complicated task ³⁴⁹. Patient safety is defined as “freedom from accidental or preventable harm due to events occurring in the healthcare setting”³⁵⁰. Healthcare industry and healthcare providers aim to reduce, if not prevent, medical errors and adverse outcomes. However, studies ^{180,351-353} performed from various perspective has shown medical errors are a serious problem ³⁵⁰, which involves multiple areas including human factors and systems engineering ³⁵⁴. In clinical and laboratory medicine, considerable time and expense is invested in institution of policies and procedures, to include detailed and often redundant patient and specimen identification and test result verification, with the specific purpose of minimizing human error ³⁴⁹. However, despite such intensive measures, “human errors continue to occur at a seemingly irreducibly small rate in medical practices, sometimes with catastrophic results”³⁴⁹. Transfusion medicine, with its intricacies is unique among clinical laboratory services in that the end result is the delivery of a biologic product that may be both lifesaving and capable of causing death ³⁴⁹. The production and delivery of blood products involves many people in several different areas of the hospital. Error prevention and patient safety in transfusion medicine have been a serious concern ³⁵⁵. There are numerous steps involved in transfusion of a blood product, including physician orders, patient identification for specimen collection by nursing or phlebotomy staff, blood bank work-up, product selection and issue, patient identification for transfusion, and, ultimately, the administration of the blood products to the patient by nursing or physician staff ³⁴⁹. Thus, errors can and do occur at any step in transfusion and any point along the way ³⁵⁵. Haemovigilance systems have emerged in the global transfusion community with the ultimate goal of improving the patient experience and outcome in blood transfusion ³⁵⁶. Haemovigilance is required to

“identify and prevent occurrence or recurrence of transfusion related unwanted events, to increase the safety, efficacy and efficiency of blood transfusion, covering all activities of the transfusion chain from donor to recipient”³⁵⁷. To incorporate haemovigilance into practice, it is necessary to incorporate information gained from the investigations and analyses to facilitate corrective and preventive actions in order to minimize the potential risks associated with safety and quality in transfusion of blood products. Such information is key to introducing required changes in the applicable policies, improving standards, systems and processes, assisting in the formulation of guidelines, and increasing the safety and quality of the entire process from donation to transfusion³⁵⁷.

2.2.1. Economics of Transfusion

Transfusion of blood products, which includes whole blood, red blood cells, platelets, plasma and cryoprecipitate, is a critical part of clinical care. In the United States, an estimated five million patients receive transfusion of blood products annually, which results in 14.5 million transfusions per year^{159,160,358}. In a 2010 statistical report by Agency for Healthcare and Quality (AHRQ), blood transfusion is among the top ten prominent coded procedures in the United States hospital discharge records. The cost of transfusion accounts for ten to fifteen billion dollars annually¹³². According to a recent study²¹ on the cost analysis of blood transfusion, the actual cost of red blood cell transfusion is 37 percent higher than previously estimated. The under-representation in the cost of red blood cell transfusion is a result of an incomplete accounting of required healthcare resources and associated activity-based costs²¹. These factors include but are not limited to, donor recruitment and qualification, blood collection, processing, laboratory testing, transportation, storage, pre-transfusion preparation, transfusion administration

and follow-up, and long-term tracking of patient outcome¹³³⁻¹³⁵. The underestimation in cost of red blood cell transfusion has the potential to misdirect program-based and strategic decision making. In addition, it has the potential to negatively affect allocation of monetary resources and cost of care calculation. A study by Goodman et al³⁵⁹ states that “nearly half of transfusion recipients in the United States are Medicare beneficiaries, and Medicare's prospective payment system is said to substantially under-reimburse hospitals for the costs associated with transfusions.” The ability of Medicare Prospective Payment System (MPPS) to accurately reimburse hospitals is dependent on the quality of cost and charge data that are reported to Medicare by the hospitals^{133,359-361}. Lack of consensus on the underlying complexity around factors associated with blood transfusion has resulted in insufficient reporting of data by the hospitals³⁶². Consequently, the insufficiency in reported data propagates inadequate accounting for the cost, resulting in under-representation of the accurate cost of blood transfusion, which in turn results in insufficient reimbursement of hospitals for the provided care.

2.2.2. Current View Points on Transfusion of Blood Products

Transfusion of blood and blood components has been a routine practice for more than half a century. The rationale behind transfusion of blood products assumes that the replacement of blood loss should be beneficial for the patient³⁶³. This assumption has constituted the underpinning of transfusion medicine for many decades³⁶³. Although transfusion blood and blood components has been a lifesaving procedure and a routine practice for more than half a century, it is not without risks³⁶⁴. It has been only over the past 20 years that we have seen a more concerted effort to answer very basic questions regarding the value of transfusion therapy.

As commonly transfusions occur in the United States, one may assume physicians practice transfusion medicine based on strict standard guidelines. However, broad variation exists regarding what type of blood components to transfuse, how much to transfuse and whether to administer transfusion at all ¹⁵². There has been a debate in medical literature concerning the appropriate use of blood components and indications for transfusion of blood and blood products ³⁶⁴. In a statement by Dr. Jeffrey McCullough, American Red Cross Transfusion Medicine Chair, author of *Transfusion Medicine*, “If red blood cells were a new drug today, it would be very difficult to get it licensed.” In a different statement by the Director of Transfusion Medicine at the University of Rochester Medical Center “For 100 years we’ve assumed blood transfusion are good for people, but most of these clinical practices grew before we had the research to support it. The current transfusion triggers were established over sixty years ago at the time when transfusion medicine was still in its infancy.” Over the past ten years scientific studies have highlighted the overuse of blood transfusion based on outdated transfusion triggers and practice guidelines ^{140,141,365}. Over the past twenty years, a growing number of single center and multicenter randomized controlled clinical trial investigations have been published to “answer very basic questions regarding the value of transfusion therapy”³⁶³. The studies are designed in an effort to optimize transfusion practices, determine appropriate transfusion indications and develop the necessary knowledge base to assess the impact of transfusion practice on patient outcomes.

2.2.3. Complexities Surrounding Blood Transfusion

Blood transfusion is a medical treatment for replacement of blood lost during surgeries, in serious injuries, and with critically and chronically ill patients ¹⁴⁰. Blood transfusion is performed with the intention of increasing arterial oxygen content in order to sustain oxygen delivery to the tissues. Blood transfusion has “undoubtedly been proven effective in many medical and surgical conditions, thereby particularly improving the survival of patients with critical impairment of tissue oxygenation” ³⁶⁶. Although blood transfusion is a common and a life-saving procedure, there are serious risks associated with it ¹⁵⁸. Transfusion reaction is defined as any adverse event or complication that occurs in relation to the transfusion of a blood component ¹⁵². Historically, infections were considered the main risk but because of the abundant donor testing and thorough donor screening, the risk of acquired infectious diseases through blood transfusion has been extremely low ^{171,367}. The major concern now is the non-infectious complications of blood transfusion which significantly contribute to adverse patient outcomes, many of which are a result of human errors and thus may be preventable or reduced ^{16,179,368}. In the field of transfusion medicine, controversy exists relative to when to transfuse, what blood or blood product to transfuse, and how much to transfuse.

2.2.4. Infectious Complications

Transfusion-transmitted infections may occur through countless numbers of agents that are transmitted to the recipient through transfusion of donated blood. These include bacteria, viruses, and parasites. A study by Maxwell and Wilson showed ³⁶⁹ “Bacterial contamination of blood components is an infrequent complication of transfusion. However, if it does occur, the potential

for fulminant sepsis in the recipient is associated with high mortality.” This can result from contamination during venipuncture or if an asymptomatic donor was bacteraemic at the time of donation. Symptoms can occur during or shortly after transfusion of the contaminated unit ^{369,370}. Red blood cells are stored at 4°C. At this temperature, contamination of Gram-negative bacteria, such as *Yersinia enterocolitica* and *Pseudomonas species* are more likely as they proliferate rapidly in this environment. Gram-negative bacteria cause infections such as pneumonia, bloodstream infections, wound or surgical site infection, and meningitis ³⁷¹. At room temperature Gram-positive bacteria such as *Staphylococcus epidermidis*, *Staphylococcus aureus* and *Bacillus* species proliferate rapidly. These are the most common bacterial contaminants of blood products. Gram-positive bacteria exist on skin flora and are transmitted to collected blood through collection needles³⁷¹. Platelets are stored at 25°C, thus Gram-positive contaminations are more commonly observed in platelets ^{369,370}. Another bacterial infection is Anaplasmosis which is caused by *Anaplasma phagocytophilum* which is transmitted to humans by tick bites³⁷¹.

Transfusion related viral infections have been greatly reduced since the mid-1980s, as result of the implementation of pre-donation questionnaires to identify high risk behaviors and pre-transfusion testing of donated blood. Examples of viral diseases that may be transmitted through transfusion include: Human Immunodeficiency Virus (HIV), Hepatitis A, B, and C, Human T—Lymphotropic Virus (HTLV I/II), Cytomegalovirus (CMV), West Nile virus, and Dengue Fever ³⁷¹. The transmission of these diseases may occur in the “window period”, which is defined as “the time after infection when the donor is infectious, but screening tests are negative” ^{369,372}.

Transmission of parasitic diseases transmitted through blood donations is rare ³⁷³. To determine the existence of these parasitic infections, donors are asked a series of questions about recent travel to areas where infections are more common. Examples of parasitic disease include: Babesiosis, Chagas Disease, Leshmaniasis, and Malaria. Prion diseases that are transmitted through blood transfusion include Transmissible Spongiform Encephalopathies, “a family of rare progressive neurodegenerative disorders that affect both humans and animals” ³⁷¹ and variant Creutzfeldt-Jakob Disease, a rare “rapidly progressing neurological disease that causes dementia and death”³⁷¹.

Studies ³⁷⁴⁻³⁷⁶ have shown transfusion reactions are under-diagnosed and under-reported in the United States. Even though the blood supply in the United States is relatively safe because the Food and Drug Administration Center (FDA) for Biologics Evaluation and Research regulates and safeguards the collection of blood and blood components against the infections, complications of transfusion remain a threat.

2.2.5. Non-Infectious Complications

According to Goodnough and Shander ¹⁵⁸, allogenic transfusion may have both a suppressive and stimulatory effect on the immune system. These effects have been referred to as “immunomodulation”. Recently immunomodulatory effects have been a major concern and the common cause of transfusion related non-infectious complications. Leukocyte mediated transfusion-related immunomodulation has been correlated with increased rate of cancer recurrence and post-operative infections. Transfusion errors have been estimated to occur with a

ratio of 1:30,000 units transfused ³⁷⁷. Hemolytic reaction remains a leading cause of fatal transfusion reaction which occurs as a result of ABO-incompatible blood transfusion. Another transfusion error is caused by the “issue of donor blood to patients from whom autologous blood is available” ³⁷⁸. Alloimmunization is more common in patients who receive multiple transfusions e.g. Sickle Cell Disease patients. The multiple transfusions result in the introduction of new antigen variants into the body. The new antigens may stimulate the immune system to produce alloantibodies against minor blood ¹⁵⁸. Alloimmunization to platelets may be caused by a large number of heterogeneous antigens, thus “transfusion of patient with preformed alloantibodies against that antigen (due to sensitization in previous transfusions) may result in delayed hemolytic reaction which has been estimated in a range of 1:1000 to 1:9000 transfusions” ^{158,379}. Transfusion associated graft versus host disease (TA-GVHD) is another complication. In ‘TA-GVHD, immune-competent HLA-incompatible donor lymphocytes are transfused to a recipient who is immunologically incapable of eliminating them” ^{158,380}. The donor lymphocytes then generate an immune response against the host cells. Transfusion Related Acute Lung Injury (TRALI) occurs within six hours of transfusion. It is “characterized by the acute onset of respiratory distress, bilateral pulmonary edema, fever, tachycardia, and hypotension in the presence of normal cardiac function” ^{158,381} as a result of increased vascular permeability. Transfusion Associated Circulatory Overload (TACO) is also characterized by pulmonary edema and respiratory distress. This is caused by increased central venous pressure and pulmonary blood volume, resulting in fluid extravasation into alveolar space. TACO is estimated to occur from 1:3000 to as many as 1:10 transfusions ^{158,381}. Febrile Non-Haemolytic Transfusion Reactions (FNHTR) are the “most common cause of transfusion-associated fever which occurs in 0.1 to 1 percent of red blood cell transfusions. Other causes of transfusion

associated fevers include: allergic reactions, hemolytic reactions, bacterial contamination, cytokine-mediated, TRALI, and HLA alloimmunization”¹⁵⁸ in febrile patients. Stored blood undergoes morphologic changes, which results in the cells becoming more rigid and less pliable. Although scientific evidence remains contradictory in this area, retrospective studies have reported an increased rate of adverse clinical outcomes and a reduction in survival with transfusion of older blood units (greater than 14 days)^{158,382-388}.

2.2.6. Transfusion of Blood Products: Reactions and Fatalities

In a report by the American Association of Blood Banks and the Department of Health and Human Services in the United States, 14.65 million whole blood and red blood cells, 4.0 million fresh frozen plasma, and 1.7 million platelet doses are transfused annually³⁸⁹. Although transfusion-related fatalities have been significantly reduced, both transfusion reactions and fatalities still do occur and laboratories are required to report them directly to regulatory agencies³⁹⁰. Transfusion-related adverse events, both short- and long-term, are among the costliest contributors to health care expenditures³⁹¹. Costs associated with the long-term consequences of the adverse effects of transfusion are among the hardest to quantify^{135,392-397}. “Despite the increasing cost of blood, transfusion practices remain quite liberal¹³⁵”, varies widely in a single institution among individual physicians³⁹⁸ and from institution to institution¹⁴⁴, and are often inappropriate^{185 399-401}.

In the 2011 report by the Nationwide Blood Collection and Utilization Survey³⁷⁵, 267 transfusion-related fatalities were reported to FDA between fiscal year 2005 and 2009³⁷⁶.

Additionally, from October 1, 2010 through September 30, 2011, FDA received a total of 79 fatality reports¹⁵⁹. Of these, 69 were determined to be transfusion recipient fatalities and 10 were deemed to be post-donation fatalities^{402,403}. The percent breakdown of the 69 transfusion recipient fatalities include: 43 percent were transfusion related; 41 percent were cases in which transfusion could not be ruled out as the cause of death, and 16 percent were unrelated to the transfusion⁴⁰². An FDA report showed, Transfusion Related Acute Lung Injury (TRALI) was the leading cause of reported transfusion fatalities (43%) in recent years, followed by acute hemolytic transfusion reactions (23%)^{402,403}. Both of these reactions typically occur as a result of human error^{397,404,405}. Complications of Transfusion Associated Circulatory Overload (TACO), microbial infection, and anaphylactic reactions each accounted for a smaller number of the reported fatalities^{159,160}. Most adverse transfusion outcomes are the result of human error^{135,350}. Reactions due to human errors are often misdiagnosed or under-reported¹³⁵. Statistical studies indicate in the cases of non-infectious transfusion related reactions, specifically in minor or delayed onset of reactions, adverse transfusion outcomes are more likely to be underreported^{406,407}. The misdiagnosis and under-reporting of adverse events is alarming and has the potential to increase the number of negative transfusion related outcomes and death on an annual basis. Many of these events are potentially preventable. The estimated percentage of costs attributable to inappropriate blood transfusion has been reported to range between 9% and 44%^{220,400}. Frequent transfusions have been linked to poorer patient outcomes, including increased patient mortality^{220,408}, a higher incidence of nosocomial infections⁴⁰⁹, multi-organ failure^{410,411}, and increased length of hospital and ICU stays^{408,412,413}. Even though the number of reported transfusion fatalities in the United States remains small in comparison to the total number of

transfusions ¹³⁵, the medical and legal cost of transfusion related adverse outcomes further burdens the fragile healthcare system ¹³⁵.

2.2.7. Scrutiny of Transfusion Indications

RBC transfusion should be based on the patient's clinical condition, hemorrhage treatment need and need for improvement of oxygen delivery to tissues ⁴¹⁴. In a 2011 study, Sharma and a colleague defined indications for blood transfusion as acute sickle cell crisis (for stroke prevention), acute blood loss of greater than 1,500 milliliter or 30 percent of blood volume, and symptomatic anemia ³⁷⁹. A restrictive strategy has been defined as transfusion when the hemoglobin level falls below 7 g/dL. The aim for conservative or restrictive transfusion practice is to achieve a hemoglobin target level of 8-10 g/dL (low transfusion threshold: 7-10 g/dL) ^{149,209,415}. Conversely, a liberal strategy has been characterized by transfusion for hemoglobin levels below 9 g/dL. The liberal transfusion practice aims to achieve a hemoglobin target level of 9-12 g/dL (high transfusion threshold: 9-11 g/dL) ^{149,183,209}. For more than five decades, a hemoglobin level of less than or equal to 10 g/dL (100 gram per deciliter) and a hematocrit level less than or equal to 30 percent was accepted as minimum level, and considered a trigger for transfusion particularly in surgical settings, regardless of patient's clinical presentation ^{244,379,414}. The transfusion trigger, known as "10/30" rule, was first proposed in 1942 and was practiced until the 1980's ^{416,417}. Physicians have been practicing the "10/30" rule based on faith and tradition rather than on scientific data ⁴¹⁸. Even though "transfusion at a hemoglobin level of 10 g/dL is much less common today", according to Corwin et al. ²¹⁸, only 25 percent of red blood cell transfusions occur in the range of 7.0 g/dL or less in order to maintain the hemoglobin

concentration level between 7.0 and 9.0 g/dL ²⁰⁵. The red blood cell transfusion itself is an additional independent predictor for adverse outcomes and therefore, has been referred to as the “second hit” for the recipient ^{192,419}. The two-hit hypotheses involves two separate components. The “first hit” is defined as the underlying patient characteristics ⁴²⁰, which may include “recent surgery, hypoxia, infection, trauma, malignancy, massive transfusion, cardiopulmonary disease, or bypass” ^{421,422}. These underlying conditions are believed to “activate the vascular endothelium and ultimately result in pulmonary neutrophil priming” ^{421,422}. The “second hit” is the “transfusion of blood products containing lipids, antibodies, or cytokines that stimulate previously primed neutrophils. The result is endothelial cell damage and non-cardiogenic pulmonary edema” ^{421,422}. Among general complications, blood transfusion leads to higher mortality, increased rate of ischemic complications, organ dysfunction, infections, delayed wound healing, non-Hodgkin lymphoma, and increased length of hospital stay ^{21,126,152,423,424}. Numerous transfusions are not required for these adverse outcomes to occur. Studies ^{21,126,152,423-428} have shown that complications were observed after administration of minimal (i.e. one or two) units of blood. The “decision to transfuse is often made without understanding the risk and benefits of transfusion” ⁴²⁹, as a result of the underlying complexities associated with blood transfusion for a particular patient. This leads to transfusion practices that vary widely.

Over the past two decades, blood transfusion triggers and utilization have been under considerable scrutiny as studies on the efficacy of blood transfusion show poor patient outcomes have been correlated with blood transfusion ^{181,218,265,430}. Recent studies have associated blood transfusion with a two to four-fold increased risk of postoperative infections when transfused patients are compared with non-transfused cohorts ^{18,21,181,245,428,431-434}. A dose-response

relationship study by Boucher and Hannon ⁴³⁵ showed “blood transfusions lead to increased postoperative infection, higher rates of multisystem organ failure, increased mortality, increased mechanical ventilator time, and increased length of stay”. Other studies ³⁸²⁻³⁸⁸ have highlighted decreased immune function – known as transfusion-related immunomodulation effect – in patients who have received transfusion although the intensity of the immune response varies from person to person.

2.2.8. Evidence-Based Indications for Optimization of RBC Transfusion

In 1999, a landmark randomized, controlled clinical trial study of stable adults in multicenter intensive care units (ICU) by Hébert et al. ²⁰⁵ compared hemoglobin levels of patients with 7 g/dL versus 10 g/dL; and found a “restrictive strategy of red-cell transfusion and a liberal strategy produced equivalent results in critically ill patients”. The study showed restrictive transfusion practices were as effective as the liberal transfusion strategy and demonstrated that patients were able to tolerate lower levels of hemoglobin without an increased rate of morbidity or mortality. In 2001, Wu and colleagues ²¹³ in a retrospective cohort study evaluated the effect of blood transfusion in 78,974 Medicare beneficiaries 65 years old or older hospitalized with acute myocardial infarction. They determined “patients with lower hematocrit values on admission had higher 30-day mortality rates. Blood transfusion was associated with a reduction in 30-day mortality among patients whose hematocrit on admission fell into the categories ranging from 5.0 to 24.0 percent (adjusted odds ratio, 0.22; 95 percent confidence interval, 0.11 to 0.45) to 30.1 to 33.0 percent (adjusted odds ratio, 0.69; 95 percent confidence interval, 0.53 to 0.89)”. In 2004, Corwin et al ²¹⁸ designed a multiple center, observational cohort study of ICU

patients in the United States to quantify the incidence of anemia and red blood cell transfusion practice in critically ill patients and to examine the relationship of anemia and red blood cell transfusions to clinical outcomes. The result showed the “number of red blood cell transfusions a patient received during the study was independently associated with longer ICU and hospital lengths of stay and an increase in mortality. Patients who received transfusions also had more total complications and were more likely to experience a complication”⁴¹². In the same year, an international study by Rao and colleagues⁴³⁶ was designed to determine the association between blood transfusion and mortality among 24,112 patients (in 3 large international trials) with acute coronary syndromes who developed bleeding, anemia, or both during their hospital course. The result indicated that “of the patients included, 2401 (10.0%) underwent at least one blood transfusion during their hospitalization. Patients who underwent transfusion were older, had more comorbid illness at presentation and had a significantly higher unadjusted rate of 30-day death (8.00% vs 3.08%; $P<.001$), myocardial infarction (MI) (25.16% vs 8.16%; $P<.001$), and death/MI (29.24% vs 10.02%; $P<.001$) compared with patients who did not undergo transfusion. In the landmark analysis that included procedures and bleeding events, transfusion was associated with a trend toward increased mortality. The predicted probability of 30-day death was higher with transfusion at nadir hematocrit values above 25%.” They concluded “blood transfusion in the setting of acute coronary syndromes is associated with higher mortality, and this relationship persists after adjustment for other predictive factors and timing of events”⁴³⁶. In 2008, Marik and Corwin¹⁸¹ conducted a systematic review of the literature using meta-analysis of observational studies (45 studies, 272,596 patients) to determine the association between red blood cell transfusion, and morbidity and mortality in high-risk hospitalized patients. Their multivariate analysis of data which corrected for age and illness

severity showed, “in 42 of the 45 studies the risks of RBC transfusion outweighed the benefits. The risk was neutral in two studies with the benefits outweighing the risks in a subgroup of a single study (elderly patients with an acute myocardial infarction and a hematocrit <30%). Seventeen of 18 studies, demonstrated that RBC transfusions were an independent predictor of death; the pooled odds ratio (12 studies) was 1.7 (95% confidence interval, 1.4-1.9). Twenty-two studies examined the association between RBC transfusion and nosocomial infection. In all these studies, blood transfusion was an independent risk factor for infection. The pooled odds ratio (nine studies) for developing an infectious complication was 1.8 (95% confidence interval, 1.5-2.2). RBC transfusions similarly increased the risk of developing multi-organ dysfunction syndrome (three studies) and acute respiratory distress syndrome (six studies). The pooled odds ratio for developing acute respiratory distress syndrome was 2.5 (95% confidence interval, 1.6-3.3)”. Marik and Corwin¹⁸¹ concluded that “in adult, intensive care unit, trauma, and surgical patients, RBC transfusions are associated with increased morbidity and mortality and therefore, current transfusion practices may require reevaluation”.

In 2010, Hajjar and colleagues¹⁸² conducted a prospective, randomized, controlled clinical non-inferiority trial on patients (n = 502) who underwent cardiac surgery with cardiopulmonary bypass in an ICU at a university hospital cardiac surgery referral center in Brazil in order to define whether a restrictive perioperative red blood cell transfusion strategy is as safe as a liberal strategy in patients undergoing elective cardiac surgery. The result, “hemoglobin concentrations were maintained at a mean of 10.5 g/dL (95% confidence interval [CI], 10.4-10.6) in the liberal-strategy group and 9.1 g/dL (95% CI, 9.0-9.2) in the restrictive-strategy group (P < .001). A total of 198 of 253 patients (78%) in the liberal-strategy group and 118 of 249 (47%) in the

restrictive-strategy group received a blood transfusion ($P < .001$). Occurrence of the primary end point was similar between groups (10% liberal vs 11% restrictive; between-group difference, 1% [95% CI, -6% to 4%]; $P = .85$). Independent of transfusion strategy, the number of transfused red blood cell units was an independent risk factor for clinical complications or death at 30 days (hazard ratio for each additional unit transfused, 1.2 [95% CI, 1.1-1.4]; $P = .002$). They concluded that the use of a restrictive perioperative transfusion strategy compared with a more liberal strategy resulted in non-inferior rates of the combined outcome of 30-day all-cause mortality and severe morbidity¹⁸². In 2013, Villanueva et al²²² studied transfusion strategies for patients with acute upper gastrointestinal bleeding. They compared the efficacy and safety of a restrictive transfusion strategy with those of a liberal transfusion strategy in 921 patients with severe acute upper gastrointestinal bleeding. Out of a “total of 225 patients assigned to the restrictive strategy (51%), as compared with 61 assigned to the liberal strategy (14%), did not receive transfusions ($P < 0.001$). The probability of survival at 6 weeks was higher in the restrictive-strategy group than in the liberal-strategy group (95% vs. 91%; hazard ratio for death with restrictive strategy, 0.55; 95% confidence interval [CI], 0.33 to 0.92; $P = 0.02$). Bleeding occurred in 10% of the patients in the restrictive-strategy group as compared with 16% of the patients in the liberal-strategy group ($P = 0.01$), and adverse events occurred in 40% as compared with 48% ($P = 0.02$). The probability of survival was slightly higher with the restrictive strategy than with the liberal strategy in the subgroup of patients who had bleeding associated with a peptic ulcer (hazard ratio, 0.70; 95% CI, 0.26 to 1.25) and was significantly higher in the subgroup of patients with cirrhosis and Child–Pugh class A or B disease (hazard ratio, 0.30; 95% CI, 0.11 to 0.85), but not in those with cirrhosis and Child–Pugh class C disease (hazard ratio, 1.04; 95% CI, 0.45 to 2.37). Within the first 5 days, the portal-pressure gradient increased

significantly in patients assigned to the liberal strategy ($P=0.03$) but not in those assigned to the restrictive strategy”. In a 45 day survival comparison with a liberal transfusion strategy, a restrictive strategy significantly improved outcomes in patients with acute upper gastrointestinal bleeding.

Evidence and the growing number of studies in the area of transfusion practice have contributed to a better understanding of the risks associated with transfusion of blood and blood components. It has “transformed transfusion medicine through the accelerated development of more sophisticated donor testing (i.e. ever-improving infectious disease tests), pre-transfusion testing, recipient identification, and multiple improvements in blood component characteristics and quality (i.e. leukoreduction, irradiation, pathogen inactivation). These developments have resulted in improved safety profiles for transfused components and a perception of minimal risk”³⁶³.

2.2.9. Pillars of Patient Blood Management

Patient Blood Management (PBM) programs have been introduced to ensure that every transfusion is optimized. The Society for the Advancement of Blood Management ⁴³⁷ defines PBM as “timely application of evidence-based medical and surgical concepts designed to maintain hemoglobin concentration, optimize hemostasis and minimize blood loss in an effort to improve patient outcome”. Further it is defined as “an evidence-based, multidisciplinary approach to optimizing the care of patients who might need transfusion.” It encompasses all aspects of “patient evaluation and clinical management surrounding the transfusion decision-

making process, including the application of appropriate indications, as well as minimization of blood loss and optimization of patient red cell mass”⁴³⁸. Based on the accumulating scientific evidence on the overuse of blood, liberal transfusion practices, and adverse outcomes of blood transfusion, the American Society of Anesthesiologists Committee of Blood Management²⁵⁰ and the Joint Commission⁴³⁹ have emphasized the importance of a standardized transfusion practice^{142,439}. In 2010, World Health Organization (WHO) adopted patient blood management principles to improve transfusion safety⁴⁴⁰; and in 2012 implemented a resolution (WHA63.12) in favor of patient blood management, with a “focus on the availability, safety and quality of blood products, and their safe and rational use”⁴⁴¹. The concept of PBM has been developed to address known and unknown risks of blood transfusion, preservation of national blood inventory, and constraints from escalating costs²⁴⁵. PBM aims to achieve improved patient outcomes by avoiding unnecessary exposure to blood products through effective conservation and management of a patient’s own blood.

PBM views patients’ physiological reserves as a natural valuable resource that should be conserved and appropriately managed. The concept of PBM is still evolving. According to Shander²⁵¹ and Gombotz², “an earlier definition of PBM involved the appropriate provision and use of blood, its components and derivatives, and strategies to reduce or avoid the need for transfusion, with the ultimate goal of improved patient outcome.” The recent concept has been focused on “preventative measures that will obviate the need for transfusion”²⁵¹. The goal is to employ a patient-centered pre-operative approach to optimize, conserve, and manage patient’s own blood. It aims to identify the patients who are at risk of blood transfusion and provide them with a managed plan aimed to reduce or eliminate transfusion with an acceptable risk of

anemia⁴⁴². Studies have shown low pre-operative hemoglobin levels, excessive surgical blood loss, and inappropriate transfusion practices are the underlying factors in majority of surgical patients which result in the therapeutic decision to transfuse^{2,251}. According to Isbister⁴⁴³, “allogeneic blood transfusion should be considered only when there are no options available.” Based on the above findings, Shander²⁵¹ has defined the three aspects of PBM as “optimization of hematopoiesis, minimization of bleeding and blood loss, harnessing and optimizing physiological tolerance of anemia”, commonly known as the “pillars” of PBM; more specifically (i) detection and treatment of pre-operative anemia, (ii) reduction in peri-operative RBC loss, and (iii) harnessing and optimizing the patient-specific physiological reserve of anemia (including restrictive hemoglobin transfusion triggers)^{155,209,245,264,444}. In Table 1, Isbister⁴⁴⁵ summarized the evidence-based components of the three pillars of PBM in a perioperative setting.

Table 3 - Three pillars of patient blood management.

1 st Pillar	2 nd Pillar	3 rd Pillar
Optimize Erythropoietin	Minimize Blood Loss & Bleeding	Harness & Optimize Physiological Reserve of Anemia
Pre-operative		
Identify and manage patients with anemia in a timely manner	Identify and manage bleeding risk	Assess/optimize patient's physiological reserve and risk factors
	Minimizing iatrogenic blood loss	Compare estimated blood loss with patient-specific tolerable blood loss
	Procedure planning and rehearsal	Patient-specific blood management plan including appropriate blood conservation
	Preoperative autologous blood collection in selected cases	Restrictive transfusion strategies
Intra-operative		
Time surgery when erythropoiesis has been optimized	Meticulous haemostasis and surgical techniques	Optimize cardiopulmonary function
	Blood-sparing surgical techniques	Restrictive transfusion strategies
	Anesthetic blood conserving strategies	
	Maintain normothermia unless specifically indicated	
	Autologous blood options – salvage, haemodilution	
	Pharmacological/haemostatic agents	
Post-operative		
Stimulate erythropoiesis if necessary	Monitoring and management of post-operative bleeding	Tolerance of anemia
	Rapid warming/maintain normothermia, unless hypothermia specifically indicated	Maximize oxygen delivery
	Autologous blood salvage if appropriate	Minimize oxygen consumption
	Minimizing diagnostic blood sampling	Restrictive transfusion strategies
	Haemostasis/anticoagulation management	
	Prophylaxis of upper GI hemorrhage where appropriate	
	Minimize infections	

Adapted from Isbister JP. The three-pillar matrix of patient blood management – An overview. In: setting. Sociatpopbmitp-o, ed. Best Practice & Research Clinical Anaesthesiology2013.

This matrix provides an evidence-based checklist for the decision making process to improve clinical outcomes. As various approaches to PBM continue to evolve, currently the “low hanging fruit” has been elective surgeries, where the greatest benefits can be demonstrated in improvement of patient outcomes through utilization of the above best-practice evidence in conjunction with customized clinical and personal management of individual patient cases.

Shander and colleagues^{251,446} recommended that “all treatments should be evaluated to determine their effect on improving patient outcomes as this is the ultimate objective of any intervention. Despite widespread use, allogeneic blood products have not undergone such

scrutiny, and the balance between their established risks and questionable benefits is often obscured by a quest to meet and surpass arbitrary laboratory thresholds. The result is a transfusion practice that is highly variable, costly, and likely to do more harm than good to the patients.” PBM emphasizes the appropriate use of blood and blood products with the aim of improving patient outcomes by using a multimodal approach. According to recent evidence, strategies involved in PBM are often considered a restrictive approach when compared to common or “cultural” practice. In order to be most effective, PBM requires a multidisciplinary teamwork approach in the context of an established hospital-wide program ²⁵¹.

2.2.10. The Joint Commission Recommendation for Effective PBM Programs

The Joint Commission aims to “continuously improve health care for the public in collaboration with other stakeholders by evaluating health care organizations and inspiring them to excel in providing safe and effective care of the highest quality and value” ⁴⁴⁷. The Joint Commission accredits over 19,000 health care organizations and programs in the United States and more than 400 programs internationally. The Centers for Medicare Services (CMS) recognizes Joint Commission accreditation as a condition of licensure and the receipt of Medicaid and Medicare reimbursement. Advisers to HHS Secretary Kathleen Sebelius observed that as a result of the variability that exists in transfusion practices, the Joint Commission has recognized "there is both excessive and inappropriate use of blood transfusions in the U.S. Improvements in rational use of blood have lagged."⁴⁴⁸.

In order to reduce the inappropriate use of blood transfusion, in a report by Knowles ⁴⁴⁹, “the 2012 Joint Commission and the American Medical Association have gathered a Physician Consortium for Performance Improvement National Summit on Overuse which focused on overuse as a patient safety and quality concern, and advocated PBM programs that include:

- A tool kit of clinical educational materials for physicians throughout the learning continuum, providing information on risks and benefits of transfusion and disseminating best practices and guidelines supported by evidence;
- Education on transfusion avoidance and appropriate alternatives to transfusion;
- Identification of subject matter experts to provide guidance;
- Advocacy for scheduled periodic assessments of prescriber competency and for accountability to organizational standards;
- Standardization of performance metrics, data collection and vocabulary to allow valid benchmarking within organizations;
- Measurement of individual physician transfusion practice as part of ongoing professional practice evaluation;
- Development of a separate informed consent process for transfusion that communicates risks and benefits consistent with current evidence;
- Identification of research priorities to close evidence gaps in what constitutes optimal transfusion practice”.

The metrics of the Joint Commission’s PBM performance Measures from 2011 include ⁴⁵⁰:

PBM-01: Transfusion Consent

Patients with a signed consent who received information about the risks, benefits and alternatives prior to the initial blood transfusion or the initial transfusion was deemed a medical emergency.

Numerator: Patients with a signed consent who received information about the risks, benefits and alternatives prior to the initial blood transfusion or the initial transfusion was deemed a medical emergency.

Denominator: Patients of all ages who received red blood cell, plasma or platelet transfusions.

PBM-02: RBC Transfusion Indication

RBC units transfused with pre-transfusion hemoglobin or hematocrit result and clinical indication documented.

Numerator: Number of RBC transfusion units with pre-transfusion hemoglobin or hematocrit and clinical indication documented.

Denominator: Number of red blood cell transfusion units evaluated.

PBM-03: Plasma Transfusion Indication

Plasma units with pre-transfusion laboratory testing and clinical indication documented.

Numerator: Number of plasma transfusion units with pre-transfusion laboratory value AND clinical indication documented

Denominator: Number of plasma units evaluated

Trauma patients excluded

PBM-04: Platelet Transfusion Indication

Platelet doses transfused with pre-transfusion platelet testing and clinical indication documented.

Numerator: Number of platelet transfusion units with pre-transfusion platelet testing AND clinical indication documented.

Denominator: Number of platelet units evaluated

Trauma patients excluded.

PBM-05: Blood Administration Documentation

Transfusions of blood units with documentation for all of the following:

Patient identification, transfusion order and blood ID number confirmed prior to the initiation of transfusion.

Date and time of transfusion.

Blood pressure, pulse and temperature recorded pre, during and post transfusion.

Numerator: Number of transfusion units (bags) or doses with documentation for all of the following: patient identification and transfusion order (or Blood ID) confirmed prior to the initiation of transfusion date and time of transfusion blood pressure, (pulse) and temperature recorded pre, during and post transfusion.

Denominator: Number of red blood cells, plasma and platelet units or doses evaluated.

PBM-06: Preoperative Anemia Screening

Patients have documentation of preoperative anemia screening 14-45 days before Anesthesia Start Date.

Numerator: Patients with preoperative anemia screening 14 - 45 days before Anesthesia Start Date

Denominator: Selected elective surgical patients

Cardiac patients removed.

PBM-07: Preoperative Blood Type and Antibody Testing

Patients with documentation of preoperative type and screen or type and crossmatch completed prior to Anesthesia Start Time.

Numerator: Patients with preoperative type and screen or type and crossmatch completed prior to Surgery Start Time Anesthesia Start Time.

Denominator: Selected elective surgical patients.

The seven blood measures have been added to the measure reserve library. The Joint Commission encourages use of the above PBM measures. In addition, the department of Health and Human Services is organizing further data collection efforts.

2.2.11. Challenges in Establishment of Effective PBM Program

Establishment of an evidence-based approach to blood utilization has the potential to reduce blood usage which can substantially lower hospitals expenditures and improve patient outcomes. The same blood products may be re-directed to other patients who are in need of the supply within or outside the hospital ²⁵². In order for hospitals or healthcare systems to gain a competitive advantage from PBM, a robust multidisciplinary, patient-centric, data driven approach is imperative to optimize the utilization of blood products in patients who may require transfusion and to simultaneously reduce preventable complications. Establishment of true metrics to track good practices of blood use and adherence to PBM guidelines are essential

elements of the program ²⁴⁵. The cornerstone of an effective PBM program is identification, collection, and analysis of relevant data that are captured in disparate hospital information systems ⁴⁵¹. To effectively monitor the program's performance, a performance management system consisting of measures, metrics, and Key Performance Indicators (KPIs) is required to quantitatively and qualitatively measure and track the hospital's and/or healthcare organization's progress against its goals, and to inform the stakeholders at different levels (operational, management, and executive level) in the organization of the extent of the progress ⁴³⁹. Establishment of such a program faces many different challenges. The practice of transfusion medicine extends across multiple specialties, covers diverse clinical and laboratory services, and requires data from many different departments and systems (i.e. admission, billing, laboratory, pharmacy, transfusion service, etc.) in order to provide a comprehensive view of the hospital and healthcare organization's practice⁴⁵².

Hospitals are not required to have a PBM program, but they are required to review blood use to ensure their transfusions meet appropriateness criteria established by medical staff (commonly by a transfusion committee) based on the hospital's blood utilization protocols and guidelines. However, transfusion committees in hospitals are not as effective as they have been intended to be ²³⁹. The transfusion committees often conduct cursory chart reviews of the transfusion cases and frequently fail to recognize the forty to sixty percent of inappropriate transfusions that occur in almost every hospital ^{239,453}. The ineffectiveness of chart reviews may be explained by the following reasons:

- Underlying complexities of transfusion medicine ^{152,158};

- Lack of or limited subject matter expertise; inability to understand the intricacy of transfusion practice and the latest evidence ^{217,239};
- Lack of proper knowledge and training to identify relevant metrics, and key performance indicators ^{239,435,453};
- Outdated and inappropriate transfusion criteria and guidelines, such as a single lab value as a reference point for appropriate use of blood (i.e. hemoglobin level) ^{435,453};
- Ineffectiveness of single chart reviews without holistic view of hospital's transfusion practice at multiple granular levels ⁴⁵³;
- Uncompensated physicians' review time ⁴⁵³;
- Organizational culture ²³⁹;
- Reviewers' bias (when physicians review the work of physicians they know, and with whom they may have economic, political, social, referral relationships ^{239,453};

Another significant impediment pertains to the aggregation of many different critical data elements residing in disparate hospital information systems making data management and analysis a significant hurdle ⁴⁵². Manual data collection and analysis is not feasible and sustainable. It requires alignment of staff and resources in order to accomplish an arduous process on an ongoing basis. The process is time consuming, challenging, inefficient, and costly ²⁵⁸. A further challenge is the regular provision of the meaningful, actionable information needed to guide transfusion practice and promote a sustainable behavioral change ⁴⁵². The meaningful presentation of information is critical for informed decision-making in order to provide a baseline for current practice, to support future improvement initiatives, and to permanently change behavior. Many healthcare organizations lack such a reporting mechanism.

2.3. Implementation Challenges of EBP in Current Health Information Ecosystem

After years of underinvestment in information systems, large-scale health infrastructure initiatives have emerged and with it have brought dramatic change to healthcare. The use of internet and health information technologies have empowered providers and patients to have a wealth of information literally at their fingertips ⁴⁵⁴. It is believed harnessing the power of information technology and incorporating it into clinical medicine will improve the delivery and outcomes of health services. This stems from the belief that changes in knowledge must trigger changes in health practices, and, as a result, altered practices must improve outcomes. In other words, “better information begets better health through the medium of better choice” ⁴⁵⁴.

The national healthcare reform initiatives in the United States have placed evidence-based health information systems and practice among the top deliverables for this decade. ⁴⁵⁵. Historically, care of the patient was influenced by the experiences and opinions of those involved in providing treatment ^{77,456}. Evidence-based practice marks a shift among healthcare professionals from a traditional emphasis on authoritative opinions to an emphasis on data extracted from prior research and studies ^{77,84,457}. However, evidence-based decision making and practice face a multitude of challenges. Evidence-based practice requires that the healthcare decision maker discern better from worse information, use that knowledge to trigger a change in clinical practice, and evaluate the outcome. To make the shift, it is integral for the individual (physicians and other healthcare providers) to embrace critical thinking values of ⁴⁵⁸:

- Courage: Critically appraise claims regardless of negative reactions;
- Curiosity: An interest in deep understanding and learning;

- Intellectual empathy: Accurately understanding and presenting the views of others;
- Humility: Awareness of the limits of knowledge including our own; lack of arrogance (e.g. promoting false claims of effectiveness);
- Integrity: Honoring the same standards of evidence to which we hold others;
- Persistence: Willingness to struggle with confusion and unsettled questions.

On the organizational level, in order for the decision maker to make the better choice they must be supported with evidence convenience (all the right information available in the right place at the right time), discrimination (the relevant and important information filtered by the unique needs of community, group, and individual), and integration (evidence embedded in work flow with its use monitored and effective evidence behaviors correlated with health outcomes) ⁴⁵⁵. In order to provide evidence convenience, discrimination, and integration at the point of decision making, a variety of health information technologies and approaches are necessary to facilitate: (i) simplicity with uncluttered, straightforward, and consistent presentation of information using an intuitive interface that requires a minimum effort to use without training; (ii) accessibility with rapid access wherever healthcare decisions are made; (iii) sensitivity to individual and group information preferences; and (iv) efficiency in the organization of information resources to reduce the healthcare professional's burden of information management ⁴⁵⁵.

Information systems are the key to evidence-based practice ⁴⁵⁹. Information systems can capture, transform and maintain data at three levels: raw data, processed data, and knowledge ⁴⁶⁰. "If the raw data is valid, then the processed data, or "information", can be considered as equivalent to evidence. Knowledge is information (evidence) in context"⁴⁵⁹. Information and knowledge management is at the heart of physician and other healthcare providers' intellectual and practical

activities. The applicability of all the available “best evidence” in a particular care management setting requires other information as well, which may be of a contextual, local, or organizational nature. “The integration and exchange of clinical and administrative best practice information among health professionals outside the restricted scope of the technical and scientific literature has been shown to be a significant factor in appropriate decision-making” ⁴⁶¹.

To embed evidence into practice, an iterative approach must be developed to empower the decision-makers to “know what to do (best evidence on best practices must be available to inform decision making), do what is known (recognize problems, formulate questions, select resources, and apply knowledge appropriately), and understand what is done (health choices and outcomes must be iteratively validated)” ⁴⁵⁵. There are six major categories of information systems and technology that contribute to evidence-based practice they include: reference databases (biomedical literature, clinical trials review, current research, etc.); contextual and case-specific information (individual patient medical records); contextual information (environment, anthropology, epidemiology, socioeconomic, etc.); clinical data repositories (clinical databases from different units or departments); administrative data repositories (claims, billing, finance, etc.); and clinical decision support systems (web-based interactive health information). ⁴⁵⁹. According to a WHO 2015 report on health evidence networks by Michelsen and colleagues, ⁴⁶² the process from data provision to dissemination of information (from data to information and knowledge) should be integrated. Integration has to take place at each step of the process. Data have to be collected and integrated in datasets. Datasets have to be consistent (both operationally and conceptually) and comparable. Different types of data, even across jurisdictions, have to be collected in a well-coordinated manner to minimize overlaps and allow

datasets to be combined in order to compare different populations or health service providers, to monitor developments over time, or to analyze correlations, and to determine the social determinants of health and the health status of patient or population groups. The approach to the utilization of clinical and management health information is still a complex, chaotic, and controversial subject ⁴⁵⁹. It is not surprising that many expectations with regard to the “contribution of health information systems to clinical practice have not been fulfilled” ⁴⁵⁹.

2.4. Implementation of Evidence-Based Patient Blood Management Program

Patient Blood Management is defined as “a multidisciplinary, evidence-based approach to optimizing the care of patients who might need blood transfusion”⁴⁶³. Recent studies point to a risk profile associated with the use of blood products ^{142,164,245,251,364}. There is increasing evidence that inappropriate blood transfusions may contribute to increased risk of morbidity and mortality ^{142,197,218,464}. There is, therefore, a need to review transfusion practice in order to identify opportunities for improved patient outcomes and to reduce costs. The key component of PBM program is a successful employment of a performance measurement system to track blood product utilization, transfusion appropriateness, providers’ performance, and patient outcomes. Effective data integration, data management, and analytics play a critical role in the evaluation of best-practice evidence, the improvement of performances, and the assessment of quality outcomes. Aggregation and analysis of data, presentation and interpretation of information through different measures and indicators allow healthcare professional and healthcare system identify and recognize the shortcomings of the system, target areas for improvement, and make corrective adjustments to address the shortfalls.

However, the diversity of data and disparity of sources in the healthcare information ecosystem pose a significant challenge for implementation of an evidence-based program. Cross-disciplinary evidence-based programs such as PBMs span multiple specialties (i.e. across departments), cover diverse clinical and laboratory services, and require data both from multiple departments in the business side and the clinical side. The types of data sets that are required for PBMs reside in disparate systems (e.g. admissions, billing, laboratory, pharmacy, transfusion service, surgical scheduling, etc.) and are not linked. These systems have their own databases, data architecture, and applications that are different from one another and at times incompatible. As a result, the limited data exchange between disparate information systems creates barriers to tapping into all the required information that has been captured relative to physicians and other healthcare providers practicing transfusion medicine and the patients who receive various blood products. This makes it very difficult to evaluate physicians' transfusion practices, patients' quality of outcome, and total costs.

In order to optimize and sustain transfusion medicine best-practice and change providers' behavior, there is a need to aggregate clinical, financial, and operational data into a common platform, develop an evidence-based performance measurement system to track practices against best-practice guidelines, and evaluate the observed changes using analytics to address the variability that exists in the practice of transfusion medicine. Such an effort requires an approach, that (i) brings together targeted data from disparate information systems, (ii) uses methods to measure performance, track patient's outcomes, and evaluate level of adherence to evidence-based best practice guidelines; (iii) provides a meaningful presentation of processed information

back to stakeholders; (iv) uses targeted education to inform healthcare providers of their practices; (v) supports program oversight; and (v) employs an analytics framework to evaluate changes in transfusion medicine practice resulting directly from the program, to fine tune areas for improvement, to evaluate patient quality of care, and to avoid unintended consequences and outcomes. In addition, it is important to keep the process collaborative and constructive as the healthcare institutions and the providers work toward the common goal of eliminating unnecessary transfusions ⁴⁶⁵.

Chapter 3: Methods

3.1. Rationale

The shift toward evidence-based practice (EBP) empowers healthcare practitioners to move from a culture of delivering care based on tradition, intuition, and authority, to a system in which decisions are guided and justified through the best available evidence ⁴⁶⁶. The concept of EBP emerged in the early 1970s as a means to improve clinical practice ^{74,298}. Despite the great advantages of EBP, many healthcare professionals remain cautious about embracing the model. The complexities of changing to practice based on evidence make it a daunting task ⁴⁶⁷ with barriers such as: attitudes toward EBP and research, unmet consumer demand for evidence-based care, logistical and organizational considerations, requirements of institutional and leadership support, current policies and procedures, access to appropriate evidence ⁴⁶⁸, and technologies needed to support EBP. There are also challenges with implementation of EBP including dissemination of EBP, audit of EBP approaches, and evaluation of associated outcomes. The framework developed and implemented in this study was designed to address the

challenges involved in the integration of evidence into daily medical practice through a performance management system.

3.2. Study Basis and Focus

The model presented here was developed based on the review of academic peer reviewed research literature, industry research reports and white papers on a use of performance management in healthcare and other industries. Additionally, the model was founded on the review of case studies based on the experience of professionals in healthcare and other industries who have successfully developed and implemented performance management systems. Several international governmental reports on good practices and resources dealing with the development of key performance measures to monitor healthcare quality were consulted. Furthermore, the method was designed based on the practical knowledge gained through professional experience related to this study. The model contained the critical elements that had been identified as necessary for the successful construction of an evidence-based performance management system. The factors and processes identified in this method tied strategic objectives of a healthcare institution to the latest finding in a field of interest. The method provided a mechanism for healthcare organizations to convert their data into meaningful information and knowledge that could be applied in practice.

For this study, the discipline of transfusion medicine was chosen with a specific focus on the patient blood management (PBM) approach. This study aimed to integrate evidence-based practice (EBP) approaches and relevant data-driven information into the daily practice of physicians. The paradigm of blood utilization has been shifting toward evidence-based practice

with a focus on optimal transfusion strategies and utilization of blood products. However, healthcare institutions struggle to implement a robust and scalable evidence-based PBM program to promote optimal utilization of blood products and to encourage adherence to latest evidence-based best practice. Optimization of blood product use is complex and challenging but it is an important task that has direct implications on patient safety, cost containment, and conservation of a valuable and scarce resource. The Figure 1 below highlights the key objectives, strategies, and tactics relevant to achieving the goals of a hospital wide evidence-based PBM program.

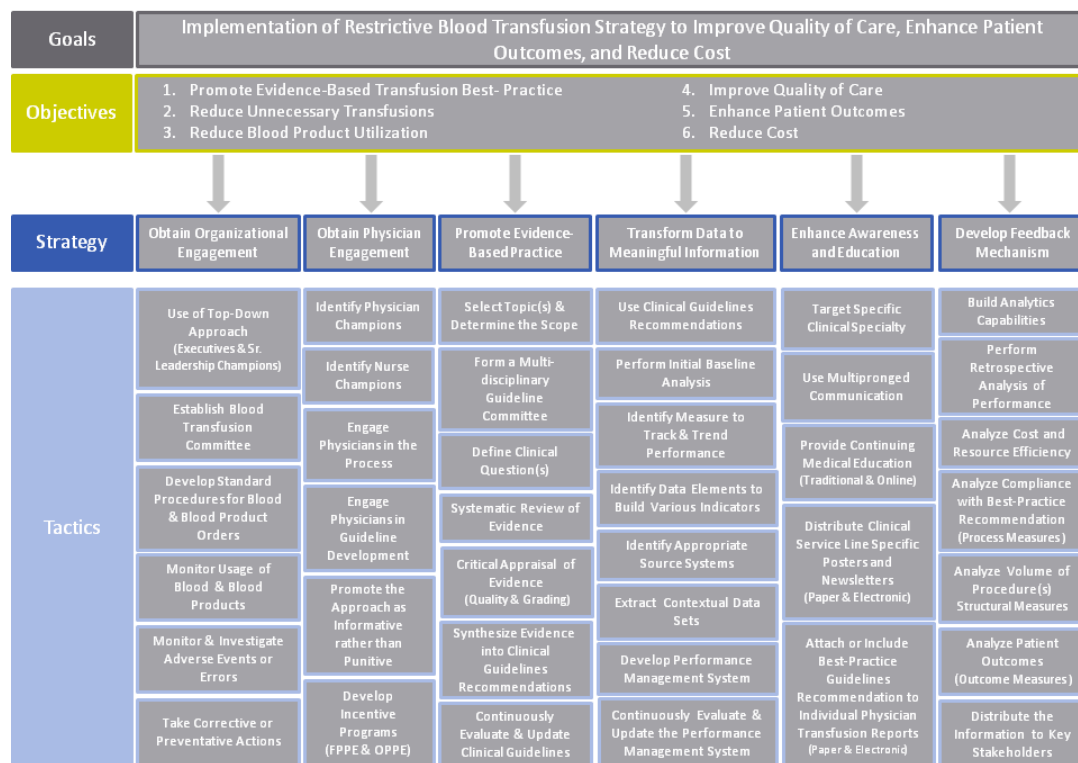


Figure 1 - Key Objective, Strategies, and Tactics for Implementation of Evidence-Based Patient Blood Management Program

3.3. Implementation Model for Hospital-wide Evidence-based Program

3.3.1. Organizational Engagement

The implementation model which is the focus of this study was put into practice through collaboration between BloodCenter of Wisconsin and a large local hospital as a pilot project. The pilot hospital was a not-for-profit, full service, short-term, acute-care facility with 396 total staffed beds. Under the pilot agreement, BloodCenter of Wisconsin agreed to create a roadmap for identification, prioritization, implementation, and assessment of patient blood management initiatives.

Establishment of an evidence-based patient blood management program required close collaboration between BloodCenter of Wisconsin and the pilot hospital. The first step was the formation of a cross-organizational management team. Figure 2 below presents a graphical diagram of the executive sponsors, operation owners, and subject matter expert team leads from different departments both at the hospital and the BloodCenter of Wisconsin; and the communication flow between the two organizations.

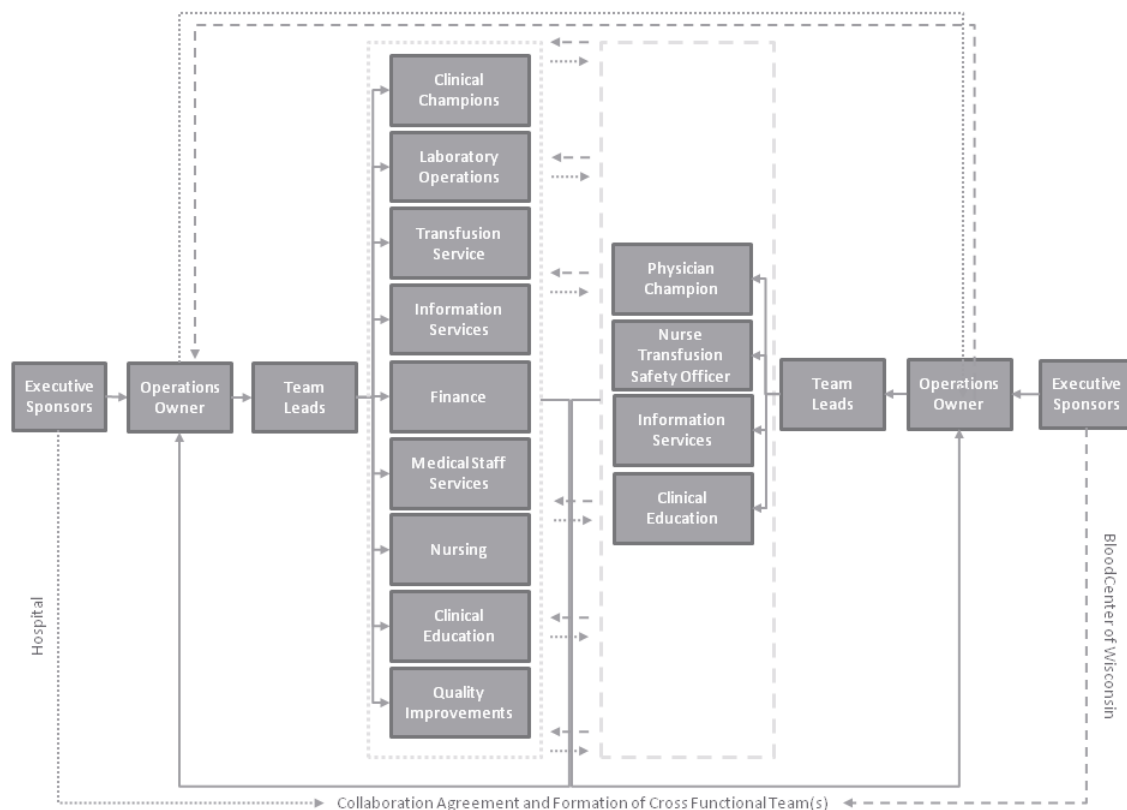


Figure 2- Conceptual diagram of communication flow between two organizations.

In order to develop a broad organizational support a Blood Utilization Governance Committee was established. The committee consisted of hospitals executives, administrative, and clinical champions including Vice President of Medical Affairs, Vice President of Laboratory, Laboratory Medical Director, Laboratory Director, Blood Bank Supervisor, physician champion, and Transfusion Safety Nurse champion. The cross-functional team consisted of a broad range of proficiencies. A clinical team including physicians and a nurse who specialized in transfusion medicine, specifically PBM were part of this core group. The overarching goal of the Blood Utilization Governance Committee was to create a culture of accountability among physicians who practiced transfusion therapies. It was very important to involve stakeholders at all levels in the process of devising the performance management system to ensure that the individuals

impacted understood the measures and metrics and the results in order for the measures to be effectively used to track and evaluate performance at multiple levels within the hospital. The chart above indicates the broad range of involvement among the two organizations Table 4.

Table 4 - Roles and responsibilities across organizations.

Hospital Roles and Responsibilities	
Roles	Responsibilities
Executive Sponsor	<ul style="list-style-type: none"> • Has a vested interest in the outcome of the project and is its champion.
	<ul style="list-style-type: none"> • Legitimizes the project's goals and objectives, is kept apprised of major activities, and is the ultimate decision maker for the project.
	<ul style="list-style-type: none"> • Promotes the project within the organization, making sure that everyone understands the benefits the project will provide.
Operations Manager	<ul style="list-style-type: none"> • Provides support to the Operations Manager and Operations Team Lead
	<ul style="list-style-type: none"> • Advocates for the business value of the project and identifies the proper resources (funding/people) and ensures they are available throughout the project

	<ul style="list-style-type: none"> • Serves as a leader in promoting and implementing Patient Blood Management and acts as an evangelist for the program within the organization
Physician Champion(s)	<ul style="list-style-type: none"> • Encourages colleagues to see the benefits associated with change and to monitor the progress of the program • Leverages data-driven information in the performance management system
Operations Team Lead (Owner)	<ul style="list-style-type: none"> • Responsible for work outside of the IT deliverables that is needed to support the implementation of performance management system (i.e., identifies Subject Matter Experts and processes that impact metrics, collaborates with the Transfusion Safety Officer on User Acceptance Testing, etc.) • Takes the role hospital's Subject Matter Expert on the metrics and leads the efforts to make the information available throughout the organization. • The Operations Team Lead is enabled to

Information System Project Manager

act across facilities.

- The Operations Team Lead and the Hospital IT Project Manager are peers who work together with the Transfusion Safety Officer and IS Project Manager to build and implement the complete solution.
- Has the authority to manage the IS project across facilities. The IT Project Manager partners with the BloodCenter of Wisconsin IT Project Manager to lead the planning and development of all project deliverables.
- Responsible for managing the schedule and all project management procedures (scope management, issues management, risk management, etc.) related to hospital resources
- IT Project Manager and the Operations Team Lead are peers who work together with the Transfusion Safety Officer and IS Project Manager to build and implement the complete solution.

Analysts/Developer	<ul style="list-style-type: none"> • Responsible for creating an initial and ongoing data feed that meets the agreed upon specification including, but not limited to, any transformations from the native format and providing evidence of the validation of source data. • Responsible for engaging the appropriate hospital technical resources as needed
Subject Matter Experts	<ul style="list-style-type: none"> • Has superior (expert) knowledge of a discipline, technology, product, business process or entire business area. • Collaborates with the Analyst/Developer to ensure that the information contained in the data feed accurately captures its intended content.
Integration Analyst	<ul style="list-style-type: none"> • Responsible for working with the Hospital Analyst/Developer and BloodCenter of Wisconsin Analyst/Developer to deliver data to BloodCenter of Wisconsin. • Responsible for engaging any additional hospital technical resources as needed

BloodCenter of Wisconsin Roles and Responsibilities

Program Director

- Responsible for all the components included in the implementation of the Program at the hospital

- Responsible expert for the patient blood management metrics and partners with the Operations Team Lead to advocate for successful implementation of the software system.

Transfusion Safety Nurse

- Advises the Operations Team Lead on process identification for accurate metric development, creating user acceptance tests with the Operations Team Lead's assistance, leads user acceptance testing, and conducts user training.

Physician Champion

- Partners with the hospital's Physician Champion to promote and implement Patient Blood Management within the organization.
- Leverages data-driven information in the performance management system to

	<p>monitor utilization data and assess the impact on patient blood management strategies</p>
Information Services Project Manager	<ul style="list-style-type: none"> • Authorize and manage the IT project at BloodCenter of Wisconsin. • Partners with the hospital's IT Project Manager to lead the planning and development of all project deliverables. • Responsible for management of the schedule and all project management procedures (scope management, issues management, risk management, etc.) related to BloodCenter of Wisconsin resources.
Analysts/Developer	<ul style="list-style-type: none"> • Responsible for ensuring that the requirements are captured and documented correctly and for understanding the business requirements and designing a solution that will meet the business needs. • Responsible for the actual building of the solution and system testing. If a need arises for additional internal technical resources,

the Analyst/Developer will engage them.

Combined Roles and Responsibilities

Governance Team

- Responsible for the entire Program and includes members of the hospital and BloodCenter of Wisconsin organizations, including executive and managers, whose purpose is to provide guidance to the implementation, ensure that functional resources are available throughout the program, remove obstacles impeding progress, and validate that the program realizes its intended benefits.
- The Governance Team includes, but is not limited to, the Executive Sponsor, Operations Manager, and Program Director.

3.3.2. Physician Engagement

The Blood Utilization Governance Committee then established sub-committees for assigning specific responsibilities to various working groups with subject matter expertise including physician group, laboratory operations, information technology, nursing quality teams.

Blood Utilization Governance Committee formed a sub-committee that included transfusion medicine expertise from BloodCenter of Wisconsin in the hospitals transfusion committee known as Transfusion Medicine Steering Committee. The role of the Transfusion Steering Committee required medical staff to take leadership role in measurement, assessment, and improvement of clinical processes related to use of blood and blood components, and to analyze all confirmed transfusion reactions. The committee included: the Laboratory Medical director, physician champions, the Transfusion Service Supervisor, a quality improvement nurse, in addition to Transfusion Safety Nurse and a physician champion from BloodCenter of Wisconsin. In addition, multiple workgroups were formed to serve a variety of purposes. The workgroups were made up of individuals with the expertise that was recognized as essential for individual project deliverables. Subject experts from multiple hospital departments (e.g. information technology, finance, lab, transfusion service, etc.) worked with well-respected physician champions who were aware of transfusion medicine initiatives and the rationale behind them. The physician champions were coupled with transfusion medicine experts (physicians and nurses) from the BloodCenter of Wisconsin to promote various initiatives among the physicians and nurses within the hospital. The workgroup members were responsible for understanding the works, planning the activities, completing the assigned work, developing timelines, setting quality expectations, informing the project management team of any issues, scope changes, risks,

or quality concerns, and proactively communicating status. Detailed definitions of the roles and responsibilities of team members were outlined in Table 2.

The BloodCenter of Wisconsin subject matter experts including a transfusion medicine physician and a nurse, quality improvement laboratory technologists, information systems analysts met with the hospital expert members from the Blood Utilization Governance Committee and the Transfusion Medicine Steering Committee in a series of joint strategic meetings to determine the strategic goals and objectives for the implementation of evidence-based transfusion medicine program. The team reviewed the hospital's goals and objectives, and identified strategies and tactics to be considered for the implementation of a hospital-wide evidence-based transfusion medicine program. The overarching goal, the objectives, and the strategies helped determine the list of tactics needed to achieve particular outcomes. Current state analysis was conducted and hospitalists were determined to be the first group of physicians to incorporate evidence-based transfusion medicine program in their daily practice.

The hospital agreed to outsource the implementation of a transfusion medicine PBM program to BloodCenter of Wisconsin. The high-level tasks involved included:

- Development of transfusion medicine best practice guidelines;
- Education of physicians and other healthcare providers on latest approaches in transfusion medicine and particularly PBM;
- Identification of data elements to track transfusion practices of physicians;
- Construction of a performance management system to track compliance with evidence and appropriateness of transfusion orders;

- Distribution of reports to physicians, other healthcare providers, and administrative staff;
- Construction of an analytics layer to evaluate changes in practice.

The hospital provided BloodCenter of Wisconsin with the resources required to aggregate, report and analyze the identified relevant data. The hospital reviewed the reports in monthly Transfusion Medicine Steering Committee meetings and took the necessary actions to help encourage adherence to best practice evidence. Quarterly meeting was held with the Blood Utilization Governance Committee to provide updates with regard to the advancement of the program and to inform of changes in practice since the implementation of the program.

3.3.3. Promotion of Evidence-Based Medical Practice

One aspect of the strategic vision was the promotion of evidence-based practice in the area of transfusion medicine at all levels of the healthcare system, particularly at the physician level. Literature has reported that substantial, unexplained variations in practice at the physician level have led to poor quality patient outcomes, inefficient care delivery, and unnecessary or wasteful expenditures^{126,140,152,155,158,183,193,209,237,433}. The area of focus of this study was the reduction in transfusion of blood products, as blood transfusion was one of the most common, resource-intensive clinical interventions in the hospital^{1,21,133-135}. The strategic objective was to implement a model that fostered a shift from authority-based medicine to evidence-based conservative transfusion strategies in order to reduce the unexplained differences in practice.

The process began with a series of continuing medical education sessions in which the hospitalists were exposed to increasingly refined information on blood transfusion practice. The presentations began with general evidence-based transfusion medicine practice, got more

specific with patient blood management strategies, and concluded with very specific training in the transfusion of individual blood components.

3.3.4. Transforming Data into Meaningful Information

Performance management is the strategic use of performance standards, measures, progress reports, and ongoing quality improvement efforts to ensure an achievement of desired results ⁴⁶⁹. It requires the active use of data to measure and improve performance across all areas of activity. In the case of transfusion medicine, the ultimate purpose of these efforts is to enhance physician knowledge on the latest evidence, improve transfusion practices, improve patient outcomes and reduce costs. While the concepts of quality improvement, accountability, and performance are not new, they are increasingly embraced by healthcare organizations to evaluate decisions, measure activities and processes, in order improve quality of care, patient outcomes, and reduce cost.

Critical elements were identified for the successful construction of an evidence-based performance management system. The framework provided a means for construction of a performance management system that tied evidence-based recommendations to metrics and indicators that informed physicians, departments, and healthcare institutions on the level of adherence to the recommendations and guidelines and provided the necessary information to evaluate outcomes of compliance both from patient care and cost containment measures. It included the following performance management components:

- Performance Standards that focused on establishment of organizational standards, goals, and targets;
- Performance Measures that focused on development, application, and use of performance measures to assess achievement of standards;
- Progress Reporting that focused on documentation and reporting of progress in meeting the standards;
- Quality Improvement that focused on establishment of program or processes to achieve quality improvement based on performance standards, measurements, and reports³⁴².

The conceptual framework below Figure 3 represented the overarching model for development, implementation, and evaluation of a performance management system as a cornerstone for implementation of an evidence-based PBM program within a healthcare institution. The activities were identified through an extensive review and analysis of literature and applied knowledge^{341,347,439,470-474}. The conceptual framework highlighted a series of activities which must be undertaken throughout the development process of performance measures to ensure successful deployment of an evidence-based transfusion medicine program. The activities follow a logical order; the order of the activities ensured the comprehensiveness of the approach. Figure 3 has been periodically referenced throughout the study as a roadmap that highlighted the intricacy involved in the development and progression of the steps that were involved in the process. Figure 3 represents a conceptual model for development, documentation, implementation, and evaluation of a Performance Management System. The modified figure was partially adapted from Health Information and Quality Authority⁴⁷².

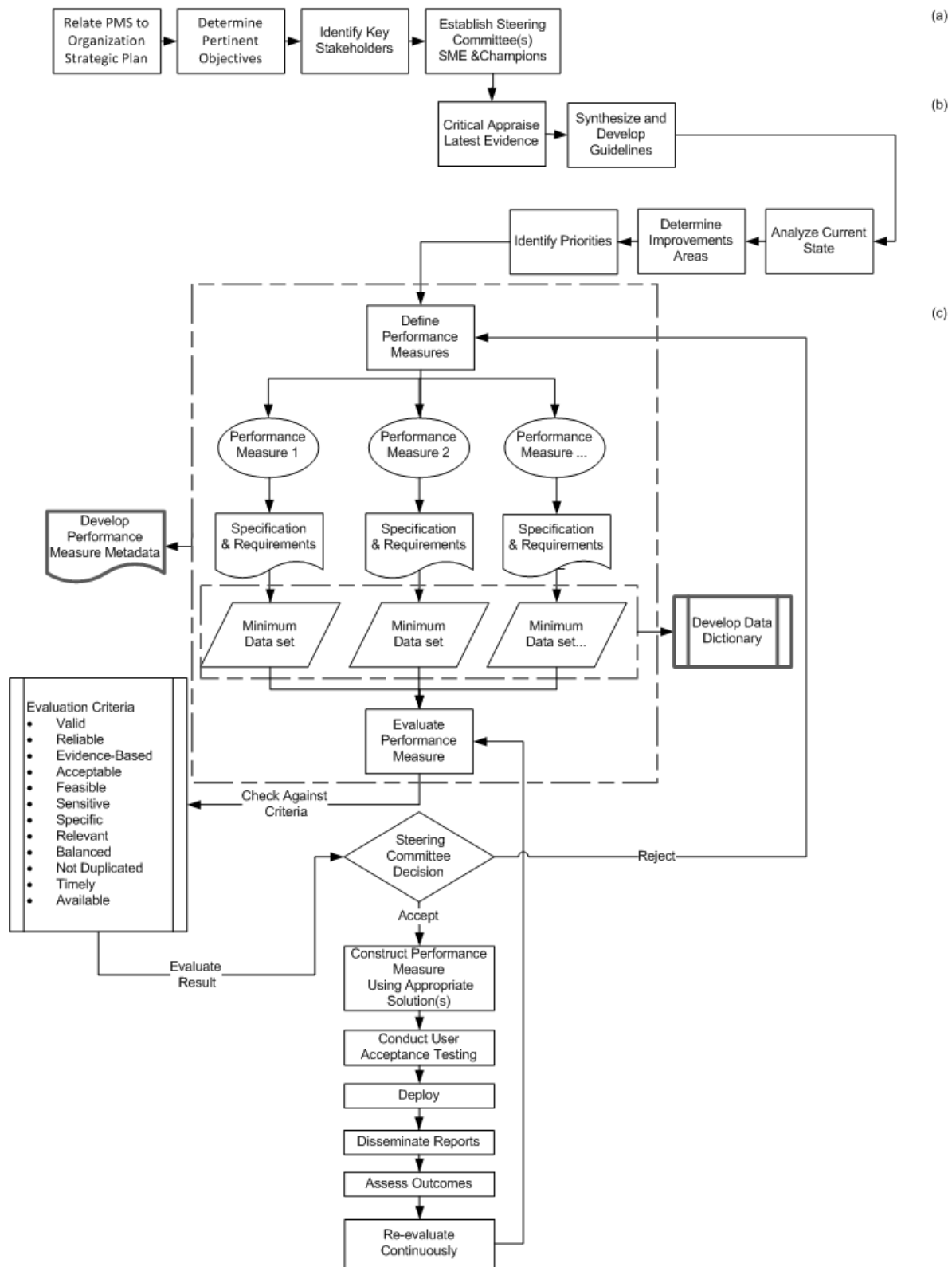


Figure 3 - Represents a conceptual model for development, documentation, implementation, and evaluation of a Performance Management System.

Evidence-based Performance Standards

Evidence-based performance standards play a foundational role in efforts to improve the quality of patient care in the United States⁴⁷⁵. Evidence-based performance standards were deployed in public and private reporting and payment systems purportedly to shape provider behavior toward doing what works and away from rendering inappropriate, even dangerous, care. They were based on scientific findings and therefore, represented an objective standard for provider behavior. Evidence-based performance standards follow the logic of evidence-based medicine as a whole. Clinical science can determine “what works,” and providers can and should replicate these findings in the care of individual patients”⁴⁷⁵.

The first component of a performance management system was the development of evidence-based standards. The evidence-based performance standards used for this study were based on the blood utilization guidelines entitled *BloodCenter of Wisconsin 2011 Adult Blood Utilization Review Guidelines* published by the BloodCenter of Wisconsin (Appendix A). The guidelines were developed by the physicians and staff of BloodCenter of Wisconsin Medical Science Institute. The evidence-based guidelines were compiled after review of the cited references and best available evidence. The review and the final approval were completed by the Medical Advisory Committee at the BloodCenter of Wisconsin. The evidence-based guidelines were used as a reference for best practices and minimum performance levels in order to encourage consistency and uniformity across various service lines. To provide easy access to references and the literature used in the blood transfusion guidelines, a commercial reference management software package, EndNote by Thompson Reuters (Philadelphia, PA), was used. An EndNote

web-based shared reference library was created to provide quick and easy access to detailed reference components used in creation of *BloodCenter of Wisconsin 2011 Adult Blood Utilization Review Guidelines*. The web-based shared reference library enabled healthcare providers to appraise and assess the validity of the guidelines or find further information on a specific topic if needed.

The use of the adult blood utilization review guidelines developed by BloodCenter of Wisconsin transfusion medicine experts as the performance standard served to address multiple barriers to the creation and use of evidence-based guidelines in clinical practice by the hospital. The use of these guidelines minimized barriers such as adequate time and ability of clinicians to review, interpret, and synthesize the available evidence, to translate knowledge into clinical practice, and to perform deductive reasoning to determine if study findings could be uniformly applied to the majority of patients in routine practice.

This study focuses on optimization of red blood cell transfusion according to the latest available evidence. Adult blood utilization review guidelines (Appendix B) stated that red cell transfusion may be appropriate for improving oxygen carrying capacity. Documentation of the indication(s) for transfusion and special circumstances for transfusion that take place outside these guidelines is recommended. Indications for transfusion of Red Blood Cell were as follows:

- Red Blood Cell Indications:
 - I. Acute Blood Loss: maintain circulating blood volume and hemoglobin concentration ≥ 7 g/dL in otherwise healthy patients; >8 g/dL in elderly patients and those with known cardiac or respiratory disease.

- 15-30% loss of blood volume: RBC transfusion likely not required;
 - 30-40% loss of blood volume: RBC transfusion probably required;
 - >40% loss of blood volume: RBC transfusion almost certainly required.
- II. Stable hospitalized patients including those in the critical care unit: hemoglobin ≤ 7 g/dL. Patients with co-morbid conditions such as coronary artery disease, pulmonary disease, or evidence of acute MI have less tolerance for anemia.
- III. Peri-operative transfusions:
- Hemoglobin concentration < 7 g/dL: RBC transfusion usually required;
 - Hemoglobin concentration 7-10 g/dL: RBC transfusion may be appropriate if any of the following are present: organ ischemia, increased potential for or ongoing blood loss, volume status and risk factors for complications of inadequate oxygenation;
 - Hemoglobin concentration > 10 g/dL: RBC transfusion usually unnecessary.
- IV. Symptomatic anemia in a normovolemic patient (generally symptoms from anemia do not occur when Hgb ≥ 10 g/dL).
- V. Outpatients with bone marrow failure may be prophylactically transfused to maintain Hgb > 7 g/dL.
- Outcome Indicators:
 - I. Improvement in clinical status of patient (relief of symptoms of decreased oxygen carrying capacity);
 - II. Improvement in Hgb/Hct (one unit of red cells should raise the Hgb on average 1g/dL or Hct 3% in an adult). One hour post-transfusion Hgb is equivalent to one

drawn within 24 hours of transfusion if there is no ongoing blood loss in a normovolemic patient.

- Comments:
 - Transfusion of a single unit may be sufficient; transfusion of additional units should be based on clinical assessment of patient. Avoid transfusions based solely on Hgb or Hct value.
 - Transfusions should be performed only after appropriate alternative therapies have been considered (e.g. iron, vitamin B12, folate and erythropoietin).
 - Certain patient populations (e.g. patient with hemoglobinopathies) may tolerate lower hemoglobin thresholds and transfusions in such patients should not be based solely on hemoglobin values.

Initial Baseline Analysis

A current state analysis was conducted to understand the hospital's transfusion practices. High level data was collected to evaluate the total number of units of blood product the hospital purchased and the cost per unit, and high level analysis was conducted of the number of transfusions. Lean methods⁴⁷⁶ were used to evaluate the work processes, including value stream maps, product and operator process flow analyses, and error potential analysis. Orders for testing or for blood products were analyzed and timed from the point of entry into the transfusion services department until the test results were released or the product was issued. Processes were evaluated for the percentage of value-added and non-value added time. Non-value added activities were eliminated. Processes were assessed using lean concepts to optimize inputs such as labor components, to reallocate intellectual capital in order to enhance service levels and to support more effective blood management and utilization.

Measures to Track Performance

An integrated health care system or a hospital may have several distinct levels of organization, and therefore, several distinct levels of performance measurement. The same levels will not be present in all systems, but there are some that will be common across organizations. For this study, the performance management system was designed at the system level (i.e. macro level to incorporate the healthcare organization and the hospitals) to be meaningful to the healthcare providers whose behavior was reflected in the measures. It was also designed to integrate performance measures at the operational level (i.e. micro level to incorporate individual physicians, other healthcare providers, clinical specialties, inpatient or outpatient units) with measures that could be rolled up to hospital or healthcare organization level, in order to incorporate a consistent set of messages about priorities, goals, and level of performance. Although this study focused on implementation of evidence-based transfusion practice for one hospital within a larger healthcare system, the performance management system was designed to scale up if the healthcare system decided to implement the program system-wide.

Design of Performance Measure Levels

The most macro level is the healthcare system itself which is composed of a number of different distinct operating units. Macro-level measures reflected performance across all hospitals and facilities or performance for major operating units. The macro level measures provided a whole system view allowing for assessment of transfusion of blood products across multiple hospitals using nationally accepted benchmark metrics, or for evaluation of strategic objectives and the effectiveness of individual hospitals on the strategic initiatives, etc. The next macro unit of measurement was the hospital. Measures designed for this level included quality and efficiency

measures such as rates of readmission, transfusion of blood products to inpatients and outpatients depending on their condition. The performance management system was designed so that if a hospital had a specific role within a healthcare system (e.g. mental health vs. acute medical or surgical vs. long-term rehabilitation facility), the performance measures could be identified and parameters could be changed with a focus on the unique strategic goals and mission for the specific hospital.

Although the performance management system was designed with flexibility to allow building of unique measures to address specific goals of each hospital, the same groups of performance measures (i.e. utilization, quality, inventory management, appropriateness) allowed comparison across an integrated healthcare system. The macro-level performance measures were the stable measures used to report to management and executive levels. Some concepts and measures must be kept constant over time, so that trends can be analyzed and results of various performance enhancement initiatives assessed⁴⁷⁷. Reporting frequency was set at a quarterly basis with the capability to compare the current quarter with the prior quarter and with same quarter in the previous year.

More granular level measures were built at the micro level, consisting of the measures used by departments, clinical service lines, physician groups, and individual clinicians. The micro level measures allowed analysis of groupings of physicians based on their primary role within the hospital (i.e. hospitalists, internists, cardiologists, intensivists). At this level, measures were designed to include analysis based on clinical quality of care and utilization (i.e. rate of

transfusion of different blood products, comparison of number of units issued per transfusion order, etc.).

Below the micro, clinical service line level, were measures for the analysis of individual physicians. The level above the physician level, i.e. department or clinical service line measures, allowed for rate analysis. This type of analysis was too small at the physician level to allow for calculation of meaningful rates. Physician profiling was at a low level in the organization because of sample size issues and questions related to adjustments of clinical measures for case mix differences among physicians. Therefore, to assess physician practice at this level, utilization measures, clinical lab values, and outlier measures were used to assess the appropriateness of the practice. If a physician was flagged as an outlier in the outlier measures, then a process for individual chart review was put into place for further analysis of the patient condition and evaluation of the appropriateness of physician's practice.

The micro-level measures were more dynamic. The performance management system was designed to allow setting of targets and thresholds to track performance and to facilitate retiring of measures that were no longer useful or adding measures that reflected new priorities. These measures tended to be more specific and smaller for targeted work units and specific groups of stakeholders. The micro measures tended to answer questions such as "How well is my group doing? Where do we need to focus our efforts in order to do better?" The frequency of reporting at micro-level depended on the availability of data and the information needed for stakeholders to take action. The goals of the micro-level measures were to create awareness and accountability and to encourage change at the smallest levels.

Figure 4 depicts the association between organization's strategic goals and development of a performance management system. It highlights the need for a robust and clear strategic goals and objectives to be formulated prior to development of a performance management system. A well designed performance management system can directly connect to specific components of strategic objectives and measure progress towards the overarching goal. Thus, the metrics were designed to tightly relate to the strategic goals and objectives, link with activities to outcomes, in order to influence decision making, be consistent with national benchmark metrics, and be meaningful to macro and micro level stakeholders. In addition the performance management system was designed with an emphasis on a closed feedback loop as a valuable mechanism for quantification of change and a means to inform on target areas for improvement, refinement, and to avoid unintended consequences by responding to change and outcomes rather than reacting to them.

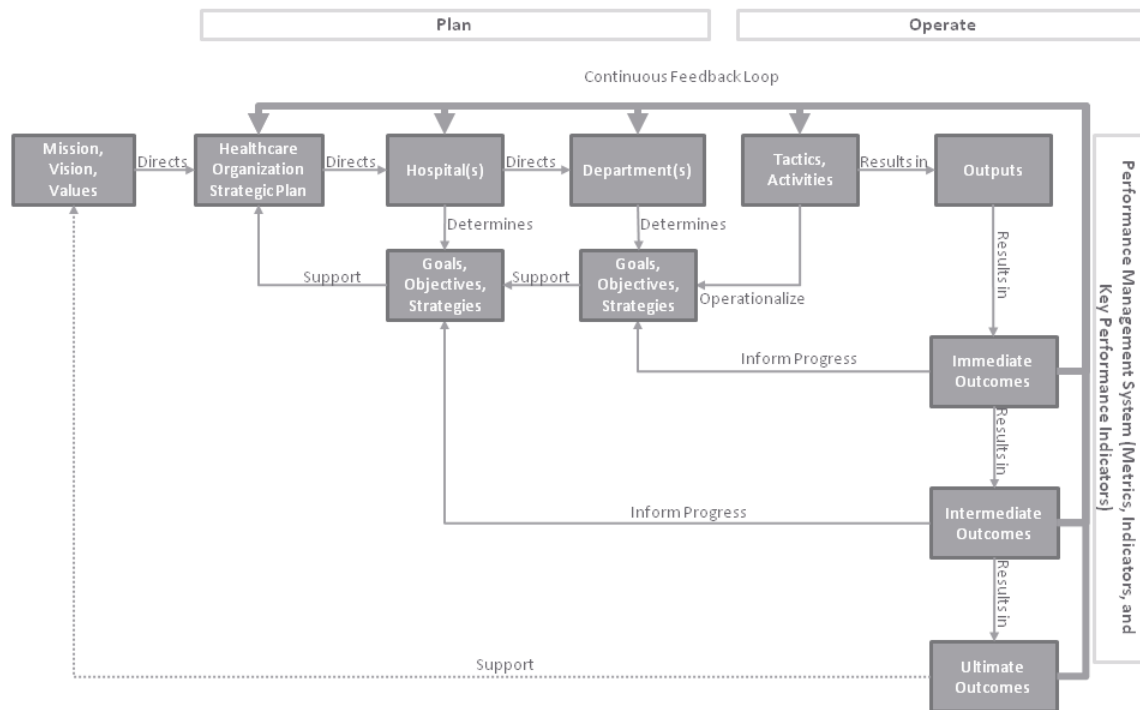


Figure 4 - Illustrates association between an organization's strategic plan and the performance management system. It highlights the continuous feedback loop as a mechanism to respond outcomes rather than react.

Data Elements and Appropriate Source Systems to Build Various Indicators

The performance management system was constructed to provide information that was significant in attaining organizational goals and priorities by representing the activities associated with each priority and measuring and reporting the outcome of those activities. Four major categories were defined for development of measures, metrics and indicators including: inventory management metrics, utilization measures, quality metrics, transfusion appropriateness indicators and key performance indicators, and benchmark metrics. Key performance indicators were the most specific of performance measures and were an important component of a

measuring performance at the micro-level (i.e. clinical specialty and individual physician). Meaningful key performance indicators had the potential to influence decision-making at the time of care by allowing physicians to consider factors deemed to be important when making decisions and by explicitly identifying desired outcomes. Development of the key performance indicators used in this study involved five key steps including; review of the strategic goals and objectives; alignment of evidence with activities and linking activities to outcomes; close involvement of key stakeholders; development of clear definition around each key performance indicators; and evaluation.

Key performance indicators were designed to tie to the hospital and clinical service line strategic objectives and required involvement of key stakeholders both on the business administrative and the clinical side of a hospital. Key stakeholders reviewed strategic goals and objectives and identified strategies and tactics for the implementation of a hospital wide evidence-based transfusion medicine program. Goals and objectives helped determine the list of strategies and tactics needed to achieve particular outcomes. Tactics and desired outcomes were considered for different levels within the organization (i.e. physicians' level, departmental level, and facility level), with key performance indicators used to measure and track individual performance. Key performance indicators were designed around the results of these identified activities to ensure that the hospital could track its success in reaching established goals and objectives. A target was determined for each key performance indicators; each target could neither be too easy nor too difficult to achieve. Where possible, key performance indicator targets were aligned with available benchmarks. Results from the key performance indicators were required to be measurable, attainable, accurate, and timely. Each key performance indicator was worded

carefully to ensure that the results being monitored were sufficiently quantifiable and specific enough to allow meaningful discussion of performance and evaluation of achievement.

The methodological framework described in this section ensured construction of an effective performance management system. The focus had been to design a series of logical steps that took into account the interconnectedness of the sequence of events involved in a set of processes necessary to achieve an objective. This was in contrast to employment of a variety of measures for separate entities to evaluate discreet and fragmented events. This section describes the fundamental building blocks in the construction of performance indicators that are repeatable measures designed to produce particular outcomes. The use of key performance indicators provided a mechanism to quantify progress towards key organizational objectives. This approach enabled corrective action to be taken if a particular process or decision failed to meet its designated outcome.

Performance Measure Documentation

Reporting outcomes with a performance management system must go beyond simply reporting inputs used during the reporting period e.g., utilization of red blood cells, output of the activity, or number of patients transfused. Instead, reporting outcomes must provide information on how these inputs and outputs have helped the hospital fulfill its high-level strategy, i.e. reducing patient days. The Performance Measure Documentation Form (Table 5) was constructed to highlight key elements for documentation of each performance measure. In all tables, including Table 5, each element has been accompanied by a definition and examples to clearly identify the type of information that must be understood, recorded, and communicated across teams and

functional areas. Performance measure specification ensures that the results reach the intended audience in the most coherent manner and format for interpretation and utilization.

Table 5 - Performance Measure Documentation Form.

Performance Measure Documentation Form	
Performance Measure Type	<ul style="list-style-type: none"> Check one: <input type="checkbox"/> Metric <input type="checkbox"/> Indicator <input type="checkbox"/> Key Performance Indicator
Title	<ul style="list-style-type: none"> Indicate the exact title
Unique ID	<ul style="list-style-type: none"> Indicate a unique identification for every performance measure Use alphanumeric format: <ol style="list-style-type: none"> Choose a prefix depending on the type of the measure APR for Appropriateness of transfusion UTZ for Utilization INV for Inventory Flow by using a three digit number starting at 001 Example: APP001, UTZ001 etc.
Version	<ul style="list-style-type: none"> Indicate version (e.g. 1.0)
Date	<ul style="list-style-type: none"> Indicate today's date
Author(s)	<ul style="list-style-type: none"> Indicate the individual(s) responsible for formulating the measure <p>Name:</p> <p>_____</p>

	Department: _____Position:_____
	Email: _____Phone:_____
Definition	<ul style="list-style-type: none"> Describe performance measure including targeted population, and the audience whom the measure is intended to inform.
Rational	<ul style="list-style-type: none"> Give rational for measurement (include references). Include reference in a sharable reference library (i.e. End-Note Web).
Objective	<ul style="list-style-type: none"> Indicate the objective behind development of the performance measure (i.e. reduction in utilization of a certain test or product by 10%).
Measure Category	<ul style="list-style-type: none"> Indicate category to which the measure belongs.
Level of Health Information	<ul style="list-style-type: none"> Indicate the level of health information (e.g. Facility, Service Line, Physicians, Encounter, and etc.).
Calculation	<ul style="list-style-type: none"> Indicate how the performance measure is being calculated. Include information on numerator and denominators, and provide information on inclusion and exclusion criteria. Indicate if there a standardized method of calculation available for this performance measure: <input type="checkbox"/> Yes <input type="checkbox"/> No If Yes, indicate if this performance measure is in compliance? <input type="checkbox"/> Yes <input type="checkbox"/> No – Provide explanation

Target	<ul style="list-style-type: none"> Establish a target for acceptable level of performance; include primary, secondary, tertiary, etc. if necessary. More specifically, the target can be initially establish based on the result of the current state (as a baseline), and improve incrementally.
Threshold	<ul style="list-style-type: none"> Establish threshold to indicate minimum level of performance. Threshold can be established according to best-practice guidelines.
Graphical Presentation	<ul style="list-style-type: none"> Indicate best type of visual presentation for the information.
Intended Audience	<ul style="list-style-type: none"> Indicate target audience whom this measure is intending to inform.
Approved by	Name: Date: Department: Position: Email: Phone: _____

Development of Minimum Data Set

Identification of a minimum data set was required for construction of performance measures. Data set was defined as “a set of data that was collected for a specific purpose” and a minimum data set was defined as core data elements that were essential in construction and operationalization of the performance measures,^{471,472,478}.

Once performance measures were defined based on the performance standard, the next step was to identify what data elements were required to calculate the performance measure. This task was achieved by reviewing the documentation for every performance measure in Table 3. The Performance Measure Documentation Form identified the category of an indicator (e.g. utilization measures) and the types of calculation required to build the indicator. This information enabled the identification of the data elements that were required to build the performance measure and the source systems for extracting the required data.

Once the data elements were defined, the data elements were incorporated into a data dictionary (Figure 5). The data dictionary was created as a repository of information which included data elements with their definitions and various attributes to support

consistent identification and aggregation of each data elements. Figure 5 indicates the attributes that were captured as part of the data dictionary to ensure each data element and its associated

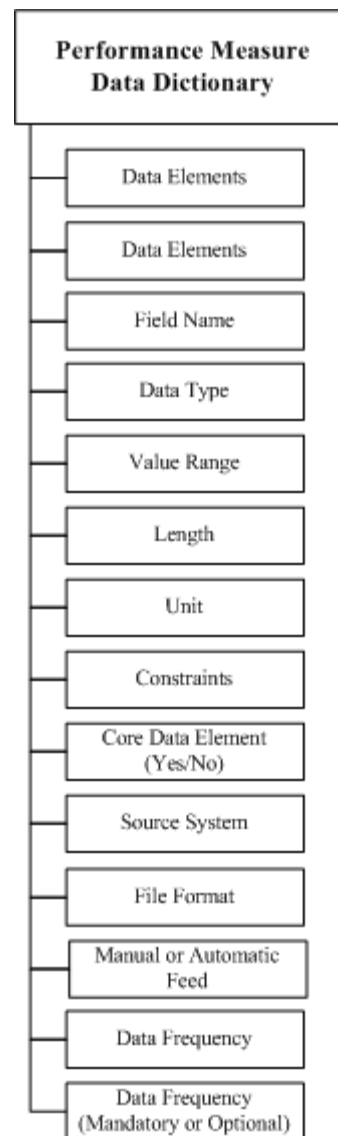


Figure 5 - Data Dictionary. Contains a list of data elements, definitions, and attributes which supports the consistent collection of data and information about the data.

values were clearly defined. Based on the information in the data dictionary, data feeds which contained the series of data elements to be extracted from a specific source system (e.g. laboratory information system, finance system, etc.) were defined. (This approach varies from one hospital to another depending on how the back end infrastructure is set up.) Once detailed information was captured, a Data Specification Documentation form was developed and used (Table 6) to document detailed information about the specific set of data elements associated with a particular performance measure. The Data Specification Documentation contained additional file format information including: the format in which data had to be collected, the frequency of collection for a particular performance measure and the contact information for the subject matter expert for the specific system.

Table 6 - Data element and data feed specifications documentation form

Data Element and Data Feed Specification Documentation	
Unique ID	<ul style="list-style-type: none"> • Use the UID from the Performance Measure Documentation Form
Data Set(s)	<ul style="list-style-type: none"> • Indicate core data elements with reference to specific sections of the Data Dictionary for complete descriptions
Data Source(s)	<ul style="list-style-type: none"> • Indicate the source system(s), where a data element and/or data set is located and extracted from
Data File Name	<ul style="list-style-type: none"> • Indicate the exact name of the file for individual data sets to be transfer
Description	<ul style="list-style-type: none"> • Include a brief explanation of file content • Indicate whether manual or IT supported feed

File Format	<ul style="list-style-type: none"> Indicate the format of the file(s) e.g. .dat, .txt, .csv, .xls, .xml. and etc.
Data Collection Frequency	<ul style="list-style-type: none"> Indicate the required frequency of data collection <input type="checkbox"/> One-Time <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Biweekly <input type="checkbox"/> Monthly <input type="checkbox"/> Quarterly <input type="checkbox"/> Annually <input type="checkbox"/> Other – Provide details:_____
Contact Information	<ul style="list-style-type: none"> Include the individual(s) responsible for collection and extraction Name: _____ Department: _____ Position: _____ Email: _____ Phone: _____

Reporting on Performance Measures to Stakeholders

The next step was to define reporting specifications and the level of health information needed for reporting purposes. Once performance measures were defined as part of the process, a plan was outlined on how and when to disseminate the results of measurements to the intended audience. Table 7 specifies details and definitions on reporting criteria for each performance measure. Reports were designed to provide information to multiple audiences rather to an individual. The reporting period and the frequency of publication of the results ensured information was made available to the audience in a timely manner.

A listing of all reports on which a specific performance measure was used to report ensured relevancy of information and provided certainty that the information needs of all stakeholders were being met without any duplications or replication. Literature ⁴⁷⁹ suggests that when reporting off the same data to various audiences, relevant information should be provided that speaks to each of the various audiences (e.g. physicians versus quality improvement personnel). In this instance, physicians better understood information with more clinical detail as compared to quality improvement personnel who needed the same information at a more summarized level. The purpose of each report was to inform each of the audiences from diverse backgrounds on the available and relevant information so improvement can be made. Reporting dashboards were an example of a method that can be effective in presenting information in a way that facilitates informed decision making to various audiences. With dashboards, the outcome of performance measures could be presented graphically through a series of charts, gauges or tables. The graphical presentation of information facilitated comparison of actual performance against desired results.

Table 7 - Reporting specification documentation form.

Reporting Specification Form	
Unique ID	<ul style="list-style-type: none"> • Use the UID from the Performance Measure Documentation Form.
Fiscal Year	<ul style="list-style-type: none"> • Indicate organization's fiscal year.
Reporting Period	<ul style="list-style-type: none"> • Indicate the period in which data applies <ul style="list-style-type: none"> <input type="checkbox"/> Real-time (Information reported as data generated) <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Biweekly <input type="checkbox"/> Monthly <input type="checkbox"/> Quarterly

	<input type="checkbox"/> Annually (Information is reported within the indicated time period) <input type="checkbox"/> Monthly in arrears <input type="checkbox"/> Quarterly in arrears (Information is reported in the following time period) <input type="checkbox"/> Other – Provide details: _____
Reporting Frequency	<ul style="list-style-type: none"> Indicate the required frequency for reporting. <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Biweekly <input type="checkbox"/> Monthly <input type="checkbox"/> Quarterly <input type="checkbox"/> Annually <input type="checkbox"/> Other – Provide details: _____
Frequency of data processing & analysis	<ul style="list-style-type: none"> Indicate the frequency of data processing based on the reporting frequency chosen above. <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Biweekly <input type="checkbox"/> Monthly <input type="checkbox"/> Quarterly <input type="checkbox"/> Annually <input type="checkbox"/> Other – Provide details: _____ If applicable, indicate the frequency of analysis based on the reporting frequency chosen above. <p>For instance it may be practical to aggregate data on daily basis, but for comparison purposes it may be appropriate for the data to be analyzed on weekly, monthly, annually, bi-annually.</p> <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Biweekly <input type="checkbox"/> Monthly <input type="checkbox"/> Quarterly <input type="checkbox"/> Annually

	<input type="checkbox"/> Other – Provide details:_____
Method of Analysis	<ul style="list-style-type: none"> Indicate in detail the method, in which performance measure is computed.
Type of measure	<ul style="list-style-type: none"> Indicate the type of measure (i.e. rate-based, count based, and etc.).^{472,479} <ul style="list-style-type: none"> <input type="checkbox"/> Proportion Measures <p>This type of measure allows comparison among organizations or trends over period of time. This measure requires both a numerator and denominator. The measure identifies target population, the time period, which the event may take place (e.g. proportion of cardiovascular surgery patients who were transfused). This type of measure often is expressed as a percentage and the numerator is contained in the denominator.</p> <input type="checkbox"/> Ratio Measures <p>This type of measure the numerator is not contain in denominator (i.e. ratio of cardiovascular patients transfused and not transfused)</p> <input type="checkbox"/> Count Measures <p>This type of measure includes number of events without denominators (i.e. Number of single RBC units transfused in the past month)</p> <input type="checkbox"/> Outlier Measure <p>This type of measure highlights events that are inherently</p>

	undesirable and usually warrant detailed analysis to determine why the event occurred. It indicates poor performance (i.e. Patient transfused with Hgb level above 10 g/dL)
Aggregation Level	<ul style="list-style-type: none"> Indicate the level within the system to which information must be reported (i.e. physician level, service line level, department level, organizational level, etc.).
Risk-Adjusted	<ul style="list-style-type: none"> Indicate whether risk adjustment strategy is required. ^{472,480} <ul style="list-style-type: none"> <input type="checkbox"/> Required – Provide details:_____ <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ <p>A risk adjustment strategy reduces the possibility of external factors influencing the measure and ensures that the measure is a true reflection of the process being measured. Certain characteristics may influence outcome (i.e. age, disease condition, etc.)</p>
List of reports performance measure is included in	<ul style="list-style-type: none"> List the various reports, where this measure will be used to report on performance.
Comparative Analysis	<ul style="list-style-type: none"> Indicate whether the measure is being measured in other healthcare institution or nationally for benchmarking purposes.
Monitoring	<ul style="list-style-type: none"> Indicate how often measure will be monitored and by whom. <ul style="list-style-type: none"> <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Biweekly <input type="checkbox"/> Monthly <input type="checkbox"/> Quarterly <input type="checkbox"/> Annually

	<input type="checkbox"/> Other – Provide details: <hr/> <ul style="list-style-type: none"> • Include the individual(s) responsible for collection and extraction Name: ____Department: ____Position:____ Email: ____ Phone:_____
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Evaluation Criteria

Once specifications were completed and the indicators were comprehensively defined, the next step was to evaluate the attributes of performance management system components (metrics and indicators). Table 6 outlines a list of characteristics and related questions for assessment of the different components. The criteria were partially adapted from Health Information authority,^{472,479} World Health Organization⁴⁸¹, and the Joint Commission⁴⁸⁰. Each component of PMS had to be approved based on the judgment and consensus of subject matter experts, and, if possible, potential users^{481,482}. Measures that had been selected using scientific evidence possessed high content validity relating to important aspects of the quality of care provided. Measures selected through consensus and guidelines had to have high face validity to ensure that performance measurements made logical and clinical sense based on extensive past observations. Reliability could be influenced by training, the measure's definition and the precision of the data collection methods⁴⁸³. Based on the theory of reliability, reliability could not be exact, thus had to be estimated⁴⁸⁴. Inter-rater reliability testing compared variations among different evaluators performing the same measurement, in order to identify inconsistencies among the evaluators⁴⁷². Internal consistency was used to assess the consistency across results within a test. It examined

the relationship between sub-indicators of the same overall measurement, and if reliable, there were correlation of the results. Test retest reliability compared the difference in results when the same evaluator performed the measurement at different times. The preferred method for choosing measures was through the systematic evaluation of the scientific evidence in support of a specific measure. This was achieved through rating the strength of the scientific evidence itself. For instance, an alphabetical grading scale was used to evaluate the strength of the evidence. The rating scale was determined as A through C. Measures supported by meta-analysis of randomized controlled trials, controlled studies without randomization, epidemiological studies received scores of A, B, and C respectively⁴⁸⁵. In healthcare, there may be limited scientific evidence in support of a certain measures, therefore it became necessary to benefit from expert opinions⁴⁸⁶.

Data collection feasibility was one of the critical elements of evaluation criteria. The burden of collecting the types of data elements required to construct the measure was an important consideration. However, it did not outweigh the value of information that could potentially be obtained. The driving force behind data collection programs has to be focused on continuous improvement of processes and domain knowledge, with the goal of applying that knowledge to devising improved performance management strategies. Data collection and analysis were considered as the foundation on which sound performance management system strategies could be devised and implemented. Data collection must take on a culture that begins at the onset of a key improvement initiative and is maintained throughout its life as long as it is economical. In other words, the value of information gained from the data must outweigh the cost of collection and analysis of the data.⁴⁸⁷. Cost benefit analyses was done to determine the cost effectiveness

of data collection. This included the type of approaches that were used to collect data and the limitations of the systems used for collection. Reporting arrangements was outlined, including reporting arrangements for existing data collection and frequency of data collection and analyses.

Table 8 - Performance measure evaluation criteria.

Performance Measure Evaluation Criteria	
Title	<ul style="list-style-type: none"> • .
Unique ID	<ul style="list-style-type: none"> • Use the UID from the Performance Measure Documentation Form
Version	<ul style="list-style-type: none"> • Indicate version (e.g. 1.0).
Date	<ul style="list-style-type: none"> • Indicate today's date.
Validity	<ul style="list-style-type: none"> • Does the measure what it is supposed to measure? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ </p> <p>A valid (metric, indicator, or key performance indicator) measures what it is supposed to measure and captures an important aspect of quality that can be influenced by the healthcare facility or system. Ideally performance measures selected should have links to processes and outcomes through scientific evidence.</p>
Reliability	<ul style="list-style-type: none"> • Does the measure provide a consistent output? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ </p>

	<p>The metric, indicator, or key performance indicator should provide a consistent measure in the same population and settings irrespective of who performs the measurement. Reliability is similar to reproducibility to the extent that if the measure is repeated the same result should be obtained. Any variations in the result of the metric, indicator, or key performance indicator should reflect actual changes in the process or outcome.</p>
Evidence-Based Explicitness	<ul style="list-style-type: none"> Is the measure supported by scientific evidence or the consensus of experts? <p>Score:_____ <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable</p> <p><input type="checkbox"/> Other – Provide details:_____</p> <p>Metric, indicator, or key performance indicator should be based on scientific evidence, the consensus of expert opinions among health professionals or on clinical guidelines.</p>
Acceptability	<ul style="list-style-type: none"> Is the metric, indicator, or key performance indicator acceptable? <p><input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable</p> <p><input type="checkbox"/> Other – Provide details:_____</p> <p>The data collected should be acceptable to key stake holders (i.e. Physicians, Transfusion Service, etc.) those being assessed and to</p>

	those carrying out the assessment.
Data Collection Effort and Feasibility	<ul style="list-style-type: none"> Is it possible to collect the required data? Is it worth the resources? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ <p>Required data elements must be available and accessible</p> <p>The feasibility analysis should determine what data sources are currently available, resources required to collect required data, and if they are relevant to the needs of the current project. This will include determining if there are existing metric, indicators, key performance indicator, or benchmarking processes based on these data sources.</p> <p>There should be a feasibility analysis carried out to determine what types of data are currently being collected in what format, and whether those can be leveraged, also the resources required to collect any additional required data.</p>
Sensitivity	<ul style="list-style-type: none"> Are small changes reflected in the results? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ <p>Changes in the component of care being measured should be captured by the measurement process and reflected in the results.</p>

Specificity	<ul style="list-style-type: none"> Does the measure actually capture changes that occur in the service for which the measure is intended? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ </p> <p>Changes in the component of care being measured should be captured by the measurement process and reflected in the results. The measure should be capable of detecting changes in the quality of care and these changes must be reflected in the resulting values.</p>
Results Interpretability	<ul style="list-style-type: none"> Can the rationale and the result of the measure be easily understood by the intended audience? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ </p> <p>Presentation of the results and information must be demonstrated in a meaningful manner to ensure intended audience can understand and interpret the results and information in a same manner and with no variation for decision making purposes.</p>
Relevance	<ul style="list-style-type: none"> Does a decision(s) can be made from the measure? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ </p> <p>The results of the measurement should be of use in planning and the subsequent delivery of healthcare and contribute to performance improvement</p>

Balance	<ul style="list-style-type: none"> Is there a set of measures that calculate different aspects of the service? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ <p>The final suite of indicators should measure different aspects of the service in order to provide a comprehensive picture of performance, including user perspective⁴⁸⁸.</p>
Tested	<ul style="list-style-type: none"> Have national and international measures been considered? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ <p>Consideration must be given to measures that have been tried and tested in the national and international arena rather than developing new indicators for the same purpose.</p>
Safe	<ul style="list-style-type: none"> Will an unwarranted focus on the measure lead to potential adverse effects on other aspects of quality and safety? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ <p>The indicator should not lead to an undue focus on the aspect of care being measured that may in turn lead to a compromise in the quality and safety of other aspects of the service.</p>
Duplicated	<ul style="list-style-type: none"> Has other previously developed measures been reviewed to ensure measure is not duplicated or overlapped?

	<p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable </p> <p> <input type="checkbox"/> Other – Provide details:_____ </p> <p> Prior to developing the measure, considerations must be made to ensure none of the measures are duplicated or the results overlap with one another. Individual measure should be distinct in the measure itself and the result of the measure to prevent any confusion or misinterpretation of results. </p> <p> Has consideration been given to other projects or initiatives? </p> <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable </p> <p> <input type="checkbox"/> Other – Provide details:_____ </p> <p> Prior to developing the indicator consideration should be given to other projects or initiatives to ensure that there will not be a duplication of data collection. </p>
<p>Timeliness</p>	<ul style="list-style-type: none"> Will the information be available within an acceptable time period to inform decision-makers? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable </p> <p> <input type="checkbox"/> Other – Provide details:_____ </p> <p> The data should be available within a time period to empower decision-makers to utilize the result to inform their decision-making process. (i.e. If the data is required for operational purposes, then it will be required within a shorter timeframe than data used for long </p>

	term strategic purposes).
Accreditation Usefulness	<ul style="list-style-type: none"> Does the measure provide capability to supplement or enhance the current accreditation process and support healthcare organization quality improvement efforts? <p> <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not Applicable <input type="checkbox"/> Other – Provide details:_____ </p> <p>Consensus, evidence, or guideline must provide information on the usefulness of the measure for the purpose of benchmarking or identification of best-practice.</p>
Final Consensus	<ul style="list-style-type: none"> The measure: <p> <input type="checkbox"/> Pass <input type="checkbox"/> Fail- See notes below <input type="checkbox"/> Re-evaluation Required: <input type="checkbox"/> Other – Provide details:_____ Notes: </p>

3.3.5. Identification of Information Silos

Using the method described system feasibility, analysis, and design for the transfusion medicine PBM data systems were conducted by reviewing the reporting requirements of the PBM program in relation to the available data sources. After deciphering the content of the hospital's current information systems, five major source systems were identified as holding the required data elements. The sources systems are listed in Table 9; the source systems identified and cross-examined for development of transfusion medicine performance management system.

Table 9 - List of required source systems for generation of data feeds.

Source Systems	Content
Finance Information System	Patient days and patient admission information
Health Information System	Patient encounter, discharge information
Transfusion Service Information System	Patient Transfusion and crossmatch information. Blood products inventory and wastage information
Lab Information System	Patient lab results information
Medical Credentialing System	Information on all current and historical healthcare providers

Minimum datasets were identified from each of the above systems. The datasets were sufficiently refined to enable cross-examination at levels required to ensure a contextual view of information. A single database was created at the BloodCenter of Wisconsin to collect and link the hospital's diverse source systems from existing databases in order to provide reports and perform analytics related to transfusion medicine practices.

Extract Contextual Dataset

An analytic and reporting solution was needed in order to code and construct performance measures for the study. It was necessary to aggregate relevant data and information from the hospital's diverse source systems in order to build reports and perform the analytical (e.g. statistical and quantitative) manipulations required to support informed decision making.

InSight™ is a reporting and analytics solution from Medware based in Lenexa, KS which had

been licensed by BloodCenter of Wisconsin. *InSight*TM is a performance management solution designed to optimize operational performance through presentation of trends. *InSight*TM performance management solution encompasses a back-end called DataLoader, which provides limited, non-enterprise-level Extract – Transform –Load or “ETL” capabilities. This function most readily integrates with Microsoft and SQL databases. The front end is called *InSight*, which provides a web interface to the end users as a portal to view pre-defined reports and dashboards. In addition, the solution offers array of capabilities, few include:

- Customization and dynamic viewing of reports,
- Sequential drill down capabilities on performance measures to view the information from top-level to the most granular detail levels,
- Graphical display of information,
- Interactive reporting capabilities,
- Customizable graphs and changeable time periods,
- Integrated email and export functionality to Excel.

A license agreement was drafted with Mediware (Lenexa, KS) to allow both internal (i.e. BloodCenter of Wisconsin Transfusion Medicine team) and external users (i.e. hospital’s end users) to access the portal for reporting and viewing purposes. The data sets were transferred from the hospital to BloodCenter of Wisconsin using a secure file transfer protocol (sFTP) and were stored in a central repository (Figure 6 and 7).

study data had to be moved into a different data repository, a SQL database that was located at BloodCenter of Wisconsin, for data processing, analysis, and reporting. The hospital was responsible for providing the required data on a routine basis to BloodCenter of Wisconsin for processing using a secure file transfer mechanism. In order to comprehensively complete this phase, a high-level questionnaire was drafted that was used as a discussion guide to learn about the various health information systems and other transactional systems within the hospitals. The questionnaire was aimed at identifying various source systems for aggregation of relevant data, confirming the availability of certain data elements in specific source systems and accessing support from the hospital Information Technology Department when necessary for aggregation and transfer of data. Ultimately, to successfully implement the analytics program, a cross-organizational project team was engaged. The key milestones of an implementation and the roles of individuals required for the success of an implementation were outlined and reviewed (Appendix B).

Data Transport

In order to transfer the data from the hospital to BloodCenter of Wisconsin, a Secure File Transfer Protocol (sFTP) was established for accessing and managing the data file transfers. A lightweight enterprise service bus, MuleSoft (San Francisco, CA) was employed as integration software to pick up the data files from the sFTP server and deliver them to an internal repository at BloodCenter of Wisconsin (Figure 7).

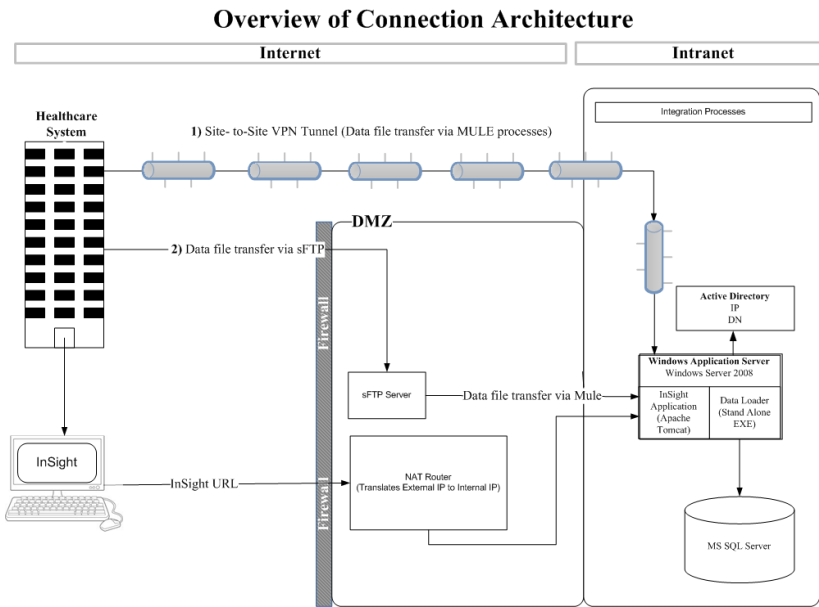


Figure 7 - Overview of connection architecture.

Data Intake

Once data was securely received from the hospital's diverse and disparate source systems, data was loaded and transferred into a data repository. This process is typically referred to as "ETL" and is the process of taking selected transactional data (both structured and unstructured) into a type of a data store (i.e. data warehouse, data mart, operational data store, analytic databases, etc.) in an organized form. More specifically, extract was the process of reading data from a database. Transform was the process of converting the extracted data from its previous form into the form it needs to be in so that it could be placed into another database. Transformation occurred by using rules or lookup tables or by combining the data with other data. Load was the process of writing the data into the target database. Data Loader offered basic ETL capabilities to perform this step.

Data Linkage

There were no direct links between patients' administrative and clinical system records. Even among clinical records there was no links among datasets from the lab information system and the transfusion service information system dataset. There was the same lack of a linkage of various events and procedures for healthcare provider among the various health information systems. Only actual blood transfusion sessions (excluding wastage) and laboratory results were linked with the administrative records which indicated blood information and laboratory results with the dates and times that fell between admission and discharge data and time. To protect patient privacy of information across the diverse source systems, a single unique identifier was created. The identifier employed a combination of patient encounter identification and facility designation. The patient medical record number, a single unique patient identifier, was only used for validation of the linkage on the back end system and was not reported.

Database Design

Once data was successfully loaded into Data Loader, they were stored in a relational SQL server database, which was considered the operational data store. A unified metadata layer was defined; and data from the various source systems were mapped to enable contextual information. Various views (virtual tables) were created to join subset of data from different tables (populated from disparate information systems) with coded logics built-in for contextual view of data, and to limit exposure to the underlying source data. The logics were coded in the views to link data on patient, provider, blood products and clinical details that were required to for individual

measures in the performance management system. Finally, the data was configured through the design of various data models to match the constructed measures.

Security Measures

Health information is very sensitive and has formal definitions around the security of patient data. Data feeds were partially de-identified to reduce the risk of exposure of patient health information. Patient identifier data elements that were used to validate patient records across different source systems were minimized. In addition, access to the data repository, Data Loader, and *InSight*TM web application were restricted through authorization and authentication. Audit services were put in place to track access to different the types of data and measures. Session timeout was placed for *InSight* web application to prevent users to remain logged in for a long period of time.

End-User Analytical Capabilities

The *InSight* application provided the end users with a portal to view pre-defined reports and a dash board. It enabled more advanced users to export data into Microsoft Excel for further analysis. Most of the capabilities have been mentioned above.

Develop a Performance Management System

Once the identified data feeds were received through the mechanism described above, the next step was to construct the performance measures (Figure 8). Figure 8 represents a simplified overview of the performance measures build process from raw data to the metrics and indicators. The construction of the performance measures followed the instruction provided by Mediware (Lenexa, KS). Briefly, Data Loader allowed administrators to setup data flows that import legacy

data into the database and perform calculations on it so that its data can be utilized by *InSight* web application. *InSight* web application allowed users to view the information using the performance measures and perform further analysis if needed for reporting and management purposes.

“Measures” were used to answer questions as to the performance of monitored services.

“Indicators” were used to give the users the information so that

they could manage performance proactively. “Data flows” indicated all the steps required to transform raw data from a text file, Excel file, or a database table, or a view into one or more measure(s). A data flow consisted of three components of “job”, “template”, and “table”. The table stored the data. The template helped transform the data in the text file, Excel file or database table/view into a table. One or more job(s) were required to perform operations on the data, including the file processing step to transform the data into the table.

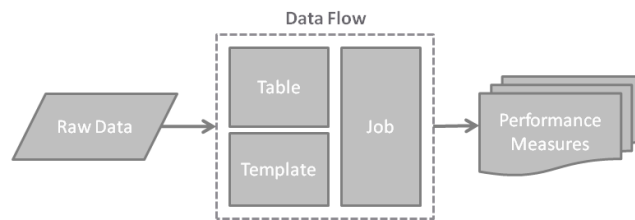


Figure 8 - Represents the conceptual view of the processes involved in building of a performance measure.

To design data flows, raw data was received from the hospital. The acceptable data sources were delimited text files, fixed width text files, Microsoft Excel files, Microsoft SQL server database or Microsoft Access both using a Microsoft Data Link (UDL) file. The table consisted of three different table structures: time series, reference tables, and hierarchies tables. Time series table held a set of information over time that measured a process. This information was typically

intended to be displayed in the *InSight* web application for the end users. Reference tables contained data whose purpose was to be mapped into time series tables. They could contain any combination of text and numerical data. Reference tables allowed the combination of data from different systems for use in a single table. The tables received and held the data. Hierarchies tables enabled drill down capabilities to provide granularity in viewing the information. It enabled the user to progressively delve into increasing level of detail.

Once the tables were set up, the next step was to develop the jobs for the import processes into the time series tables for display of the information on the *InSight* web application. Prior to publishing the information on the web application, it was important to note that both Data Loader and the *InSight* web application used tables to store table structures and their corresponding data. In this context, a table encompassed both a Data Loader table and a data table. A Data Loader table was a collection of data that represents the structure of a data table in the database. It specified the format of the table, table fields and field types contained, etc. The Data Loader table contained the meta-data for a data table. Data table was a SQL table that contained the data itself for a table. Data tables used jobs for the import of data. The template related the data fields in the source repository to data fields in a target database table. It allowed the user to link between fields, add expressions to set the value of database fields and add variables that could be used in other expressions.

All database tables were initially populated with data as specified in a template. Templates were used by the process file job step which took the data from the source system and used it to add data into a target database table. The template was the second of three arguments used by the

process file job step. A job was a set of steps that processed the data and loaded it into a table for delivery and viewing in the *InSight* web application. The job(s) were first run to populate the reference tables and then run the second time to import data into the time series table. As indicated, jobs could have one or more steps. A job always contained the ‘get parameters’ job step as the first step. The ‘get parameter’ step was not editable in the Data Loader user interface. In addition, the jobs had parameters; supplying parameter values to the job gave Data Loader the information to supply parameter values to all the steps defined for the job.

Every different step required different parameters, which had to be set individually. Common job parameters included input files, input template, and production table. The input file parameters were typically used when the job contained a process file job step to import data from a source system into a database table. The process file step defined which type of file would be obtained from the source data (i.e. file that contained a flat data file or a file that told that step where to get the data from was referred to as data link file or UDL). The input file parameter was typically used when the job contained the process file step to import source data into a database table. This parameter referred the process file step to which template should be used to map the source data to the database target table. The production table parameter told the job from which database table the data should be used. Once data flow was processed and deployed successfully, the performance measure would be ready for viewing by the end user on the *InSight* web application.

3.3.6. Awareness and Education

Healthcare Performance Management Dashboard

Performance dashboards were a component of the performance management system that enabled communication of strategic goals and empowered the stakeholders to measure, monitor, and manage key initiatives and processes required to meet objectives and accomplish tasks. Dashboards provided tailored reports that informed specific individuals or groups of administrators and healthcare professionals. For example, a clinical dashboard had to provide the capability to:

- i. Monitor defined processes and activities using measures and to show trends that identify potential problems;
- ii. Facilitate analysis of the root cause of problems by exploring relevant and timely information from multiple perspectives and at various levels of granularity;
- iii. Inform management of individuals' performance and processes to improve decisions, optimize performance, and guide the program towards the intended objective.

The next step was the integration and display of the information in a timely and meaningful manner to the intended audiences (physicians, administrators, managers, department heads, etc). *InSight* web application provided physicians, other healthcare providers, and administrators with access to the aggregated information in a form of a report which promoted informed decision making and allowed tracking trends of individual healthcare provider or service line groups. User access to the dashboards was defined for the end users using a uniform resource locator (URL).

For this study, the dashboard was utilized to monitor blood product utilization, transfusion appropriateness based on pre-transfusion lab values, quality of blood products transfused, and to

inform hospital management and administrator of the transfusion medicine practice. The dashboard was customized to take into account specific department's information needs. It was designed to provide custom reports to individual groups of stakeholders such as physicians, nurses, transfusion service lab technicians, departments, executives and the medical director of transfusion safety committee. The customization enabled a specific set of information to be presented to the intended audience. This ensured security of information and provided a means to avoid information overload which remains a barrier to healthcare providers using specialized resources. Therefore, designing the level of granularity, type of information, and method of presentation were key factors in designing dashboards that presented measures in a meaningful way while avoiding fatigue and desensitization. The dashboard followed a build instruction provided by the software vendor.

Effective Interventions to Encourage Best Practices

A multi-pronged intervention strategy was adopted to encourage continuous adherence to transfusion medicine best-practice guidelines. The strategy was based in part on an extensive review of literature on the most effective education strategies that affect physician behavior, performance, and healthcare outcomes. The search included a bibliographic search of published research and a citation review of relevant articles. In addition, past approaches of the transfusion safety nurse were evaluated to determine any correlation between educational and reporting interventions (i.e. dissemination and review of reports with department heads, individual physicians, educational newsletters, formal presentations, posters, blogs, etc.), and change in the associated transfusion practice trend. Periodic conversations with the medical director of the

transfusion committee also were used to determine best approaches and incentives to help change inappropriate transfusion practices. The intervention strategy included:

- i. Distribution of evidence-based practice guidelines as a performance standards;
- ii. Use of newsletters and posters on transfusion best practices;
- iii. Creation of continuing medical education courses on evidence-based transfusion practices;
- iv. Distribution of paper transfusion summary reports to individual physicians and department heads;
- v. Review of outlier (i.e. physicians not practicing in accordance with evidence-based guidelines) reports by the Transfusion Committee Medical Director followed, when necessary, with a formal letter citing cases and recommendations.
- vi. Creation of an environment focused on information, not punishment. (Reports would eventually be tied to Physician Performance Evaluation reviews.)
- vii. Evaluation of the effect of blinded and un-blinded reports for comparing individual physicians with their peers.

3.3.7. Develop Feedback Mechanism

In order to assess the changes in physician practice an analytics framework was developed and used to address the following fundamental questions:

- What types of improvements (quality, performance, safety) were desired?
- What processes had to change or be created to result in improvement?
- What change (if any) had occurred?

Figure 9 represents the position of the analytics framework in the context of information value chain. The goal of the analytics is to continuously improve efficiency and effectiveness of every decision and action. Figure 10 details the steps involved in the analytics framework used for this study. It begins with the emphasis on data quality, addresses cross functional inefficiencies due to heterogeneity of various information systems and data silos, emphasizes contextual development of data models, and enables use of different applications of analytics from diagnostics and, to predictive and perspective, it incorporates statistical framework to understand sources of uncertainty between observation and what actually occurred. The analytics model below took into account system of tools, technologies, techniques, and people to consistently and reliably generate data-driven information with the focus to drive clinical insight needed to take appropriate actions and achieve measurable and desired outcomes.

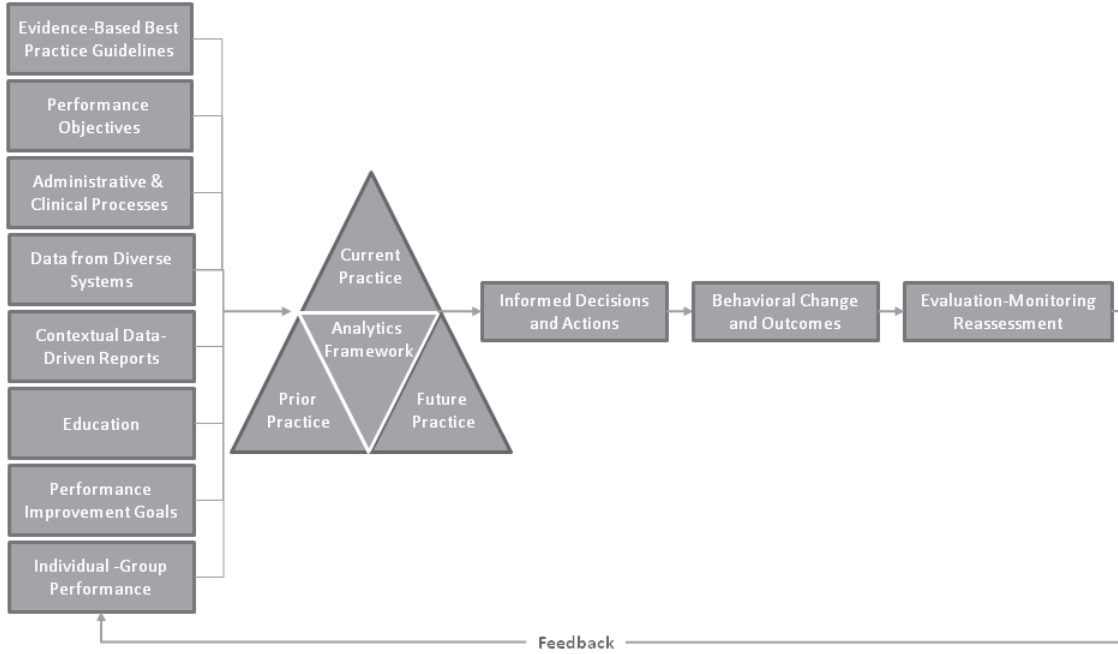


Figure 9 - Details the steps involved in building and using the analytics framework.

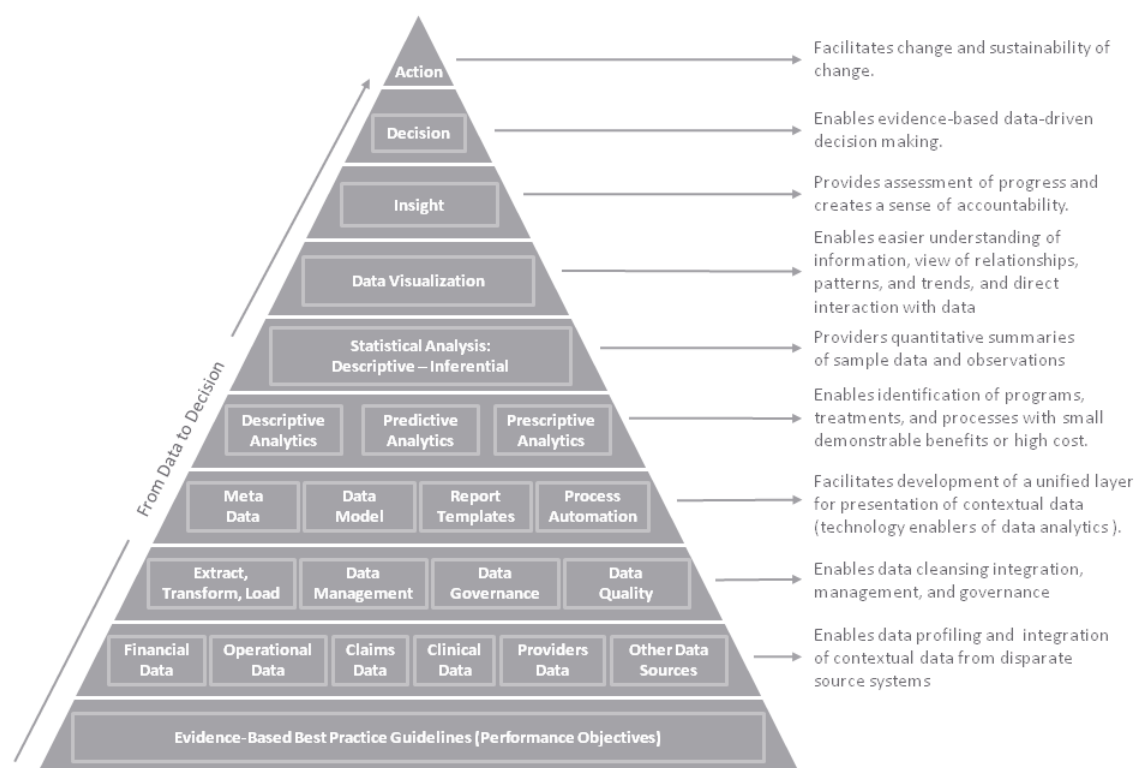


Figure 10 - Details the steps involved in building and using the analytics framework.

Moreover, the information value chain served as continuous feedback mechanism loop to evaluate changes directly impacted by the promotion of restrictive transfusion approach, to identify new areas for improvement, and avoid unintended consequences and outcomes.

3.3.8. Evaluation of Change in Physicians Practice

Evaluation of physician performance and feedback across multiple organizational levels were key components in the success of the project. Evaluation was based on the performance of hospitalists relative to the consensus RBC utilization recommendations which included:

- A restrictive transfusion strategy with a transfusion threshold of hemoglobin level of 7 g/dL, or 8 g/dL for patients with cardiac conditions.
- Order of single-unit RBC transfusions with a restrictive pre-transfusion Hgb trigger.
- Post-transfusion reassessment for determination of patients need for subsequent transfusion.

Pursuant to transfusion medicine best practices education programs, the transfusion medicine PBM performance management system tracked various aspects of healthcare providers' transfusion practices. Hospital data was actively used to develop reports and an analytical framework was used to retrospectively evaluate changes in the transfusion practices of the hospitalists. The hospitalists and department heads were provided with reports on individual physicians' which included transfusion metrics on RBC ordering on a quarterly basis. For the purpose of the global review, the report to the department chair was unblinded with identified physicians and their transfusion information; the report to individual hospitalists was blinded to allow comparison of each. Corrective feedback on the reports was provided as needed through multiple avenues including: further education, peer to peer education, formal letters from the Transfusion Steering Committee Chair, and reflection on performance evaluations.

Data analysis was conducted over a 24 month period in order to evaluate pre and post intervention periods. The time period for data collection and analysis was from October 1, 2012 to September 30, 2014. The 24 month period was chosen to take into account 12 months of pre-intervention and 12 months of post-intervention and to allow for the seasonality that was observed in the number of patient admissions to the hospital in different months. The patient type included in this study was hospitalized individuals with an inpatient designation.

Cost Analysis of Red Blood Cell Utilization

A value stream map based on lean management methods for analysis of current and future state was employed. Diagnostics, therapeutic, technical, laboratory, logistics, administrative, education, and quality activities associated with RBC transfusion ordered for patients were observed and documented by the transfusion safety officer prior to implementation of the framework. To determine activity-based cost of RBC transfusion, processes and activities associated with RBC transfusion were divided into six major categories including:

- Maintenance of blood products by blood bank including activities such as: inventory monitoring, blood components ordering, unit checking, blood grouping, returns processing, antigen screening, etc.
- Pre-transfusion activities including: physician evaluation of patient, obtaining pre-transfusion samples, sample processing, Hgb and CBC testing, and etc.
- RBC unit preparation by transfusion service including: receiving and processing transfusion order, label creation, delivery to patient, patient type and screen, reconfirmation of patient blood type, unit selection, unit labeling, etc.
- Transfusion nursing staff including: ordering transfusion, verification of entered order, consent form preparation and completion, assembly of supply, receipt and verification of blood unit, verification of match, re-identification of patient, monitoring patient vitals every 15 minutes, monitoring patient for duration of transfusion, documentation, post-transfusion assessment, transfusion reaction support, etc.
- Post transfusion activities including: Hgb and CBC testing, transport of samples to the lab, receipt and log of samples, post transfusion testing and assessment, etc.

- Other activities include: rework factor, overhead, product and supply wastage, inventory carry cost, and etc.

A cost model adapted from a landmark study that focused on an in-depth examination of the complex array of activities surrounding the decision to transfuse on transfusion activity-based cost²¹ was used to determine the cost of RBC transfusion.

3.4. Statistical Analysis

After receiving approval from the hospital under Business Associate Agreement, 24 months of data from October 2012 to September 2014 was collected for inpatient encounters (32, 870) at the institution. Neonate patients less than 1 year of age (3,652) were eliminated due to higher Oxygen binding affinity of fetal hgb. There were 11,553 inpatients whose attending physicians were hospitalists (35 physicians with hospitalist designation as primary specialty). ETL processes, mapping and linkage of data were performed prior to storage of data in a central SQL server repository using a performance management analytics portal (InSight, Medware Inc., Lenexa, KS). The central repository contained data from the hospital's diverse and disparate information source systems (including: finance, transfusion service, laboratory, medical staff services, and EHR systems). Data was extracted from the central repository using SQL queries, and was processed and analyzed using software programs including Excel statistical package (Microsoft Inc., Richmond VA), and MATLAB (MathWorks Inc., Natick, MA). Categorical variables were reported as frequencies and percentages; continuous variables were reported as means with standard deviations. Comparisons of categorical and continuous variables were done

using Pearson Chi-Square test and two sample t-test, respectively. All significance tests were two-tailed, with α level of 0.05 to denote statistical significance.

Chapter 4: Results

The study results are based on 32,870 patient encounters with inpatient status from October 1, 2012, to September 30, 2014. During this time period, 9.12% of discharged inpatients received RBC transfusions using a total of 8,905 RBC units (not including wasted units). Patient information was linked across disparate source systems using a composite unique key which consisted of the hospital facility code and an encounter identification number. Approximately 99.15% of discharged inpatients were linked to their transfusion events and clinical details.

October 1, 2012 to September 30, 2013 represents pre-implementation of an evidence-based restrictive transfusion medicine framework. October 1, 2013 to September 30, 2014 represents post-implementation of the evidence-based restrictive transfusion medicine framework period.

The post-implementation period included the following hospital-wide interventions:

- Recommended a restrictive transfusion strategy with a transfusion threshold of hemoglobin level of 7 g/dL, or 8 g/dL for patients with cardiac conditions.
- Recommended orders of single-unit RBC transfusions for non-bleeding stable medical patients with a restrictive pre-transfusion Hgb trigger.
- Recommended post-transfusion reassessment for determination of patients need for subsequent transfusion.
- Offered continuing medical education courses on the latest evidence-based approaches to transfusion medicine.
- Distributed educational and materials in the form of newsletters, posters, and flyers.
- Constructed and implemented performance management system to track and measure the evidence-based recommendations.

- Implemented transfusion medicine reporting and utilized data analytics software to analyze the trend and report on transfusion practices.
- Distributed transfusion reports targeted to individual hospitalists and department heads for all relevant service lines.
- Implemented an analytics framework to evaluate changes directly impacted by the promotion of restrictive transfusion strategies, to identify new areas for improvement, and to avoid unintended consequences and outcomes.

4.1. Performance Management System

A performance management system (PMS) was constructed to achieve the following objectives in transfusion medicine including: identification of areas for best practices, facilitation of actions to improve health services, improvement of patient care and outcomes, and assurance that operational activities are linked to the overall organizational strategies.

Specifications documents were used (Tables 3-7) to construct the different metrics and indicators as part of PMS which: helped define targets and thresholds across key aspects of service delivery including management of resources (e.g. blood products); enabled a comprehensive picture of the service lines (e.g. hospitalists) progress towards achieving goals recommended by the evidence-based best practice guidelines; provided a mechanism for early indication of emerging issues that may require corrective actions; and indicated where there was a potential to improve the cost effectiveness of services.

4.1.1. Performance Monitoring

The hospital, as part of a larger healthcare system, was composed of a number of separate and distinct levels of operating units. To accommodate the different levels of operating units, the performance measures were designed and constructed to accomplish a granular level of reporting (e.g. system, hospital, clinical service line, and individual physician) pertaining to these different units. There were dimensions that were different across service lines, but there were also dimensions that were common. The PMS system was designed and constructed to scale as additional hospitals were added in the future (Figure 11). Figure 11 represents a conceptual representation of the PMS for the hospital. It represents a combination of performance measure including: measures (e.g. Hgb, INR, Fibrinogen lab values), metrics (i.e. blood products utilization metrics), scorecards (i.e. tracking physicians' ordering of blood product transfusions), and key performance indicators (i.e. measure progress towards achieving objectives). Scorecards play a key role within a PMS. They enable translation of strategic goals into tangible objectives and measures. It allows measuring, monitoring, and assigning key performance indicators to track and optimize performance towards organizational goals.

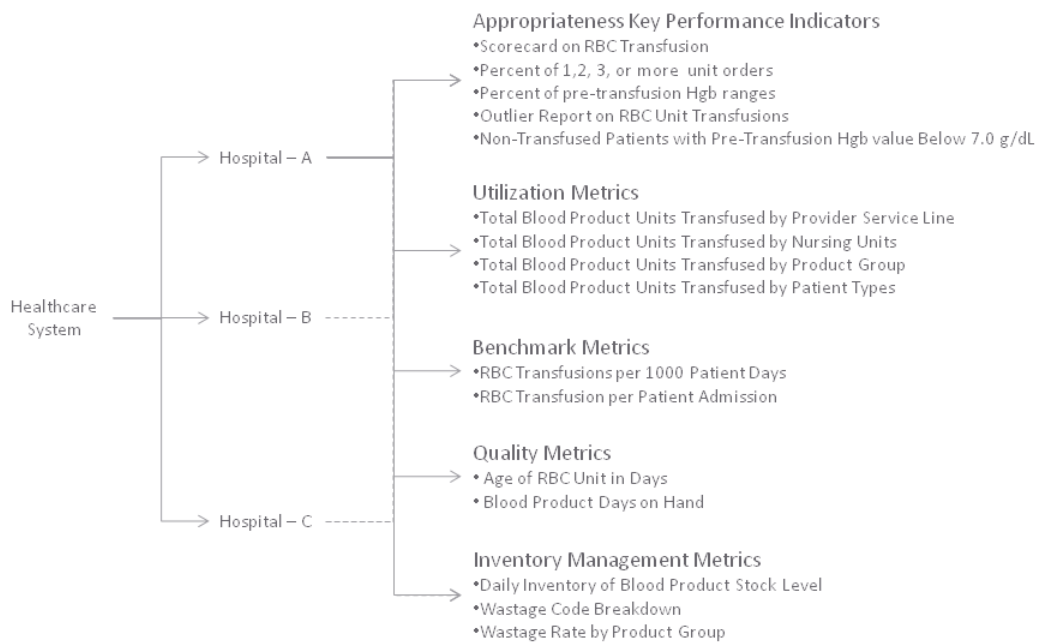


Figure 11 - Conceptual representation of the performance management system for the hospital.

The construct PMS was used to implement evidence-based transfusion medicine strategies in the hospital.

4.2. Hospital Activity Profile

4.2.1. All Inpatient Demographics and Hospital Activity Profile

The hospital's activity profile and patient demographic during the study time period are represented in Table 10 using descriptive statistics.

Table 10 - Hospital activity profile and patient demographic.

	Pre-Intervention (Oct. 2012 – Sep. 2013)	Post-Intervention (Oct. 2012 – Sep. 2013)	<i>p</i>-Value
Inpatient Admission	16827	16043	
Inpatient Gender, n (%)			
Female	9885 (58.78)	9394 (58.58)	<i>p</i> = 0.70
Male	6933 (41.23)	6645 (41.44)	
Mean Age (SD):			
Female	48.96 (27.75)	47.53 (27.60)	<i>p</i> < 0.01
Male	49.09 (28.23)	48.63 (27.87)	<i>p</i> = 0.33
Inpatient Discharges, n (%)	15631 (92.95)	14845 (92.57)	<i>p</i> = 0.79
Inpatient Mortalities, n (%)	1192 (7.09)	1194 (7.45)	<i>p</i> = 0.24
Mean Case Mix Index (SD)	1.37 (0.04)	1.39 (0.04)	<i>p</i> = 0.34

4.2.2. Transfused Inpatient Demographic and Hospital Activity Profile

Table 11 represents the demographic of inpatients who received at least one unit of RBC transfusion using descriptive statistics. The rate of inpatients that were transfused with RBC unit was significantly decreased during post intervention period $X^2(1, N = 32870) = 18.66, p < 0.01$.

Table 11 - Hospital wide transfused patient demographic.

	Pre-Intervention (Oct. 2012 – Sep. 2013)	Post-Intervention (Oct. 2012 – Sep. 2013)	<i>p</i>-Value
Transfused inpatients, n (Rate)	1648 (0.28)	1351 (0.26)	<i>p</i> < 0.01
Inpatient Gender, n (%)			
Female	979 (59.41)	791 (58.55)	<i>p</i> < 0.01
Male	666 (40.41)	560 (41.45)	
Mean Age (SD)			
Female	66.65 (19.23)	66.32 (19.11)	<i>p</i> = 0.70
Male	65.50 (16.96)	65.22 (18.21)	<i>p</i> = 0.18
Inpatient Discharges, n (%)	1351 (81.98)	1098 (81.27)	<i>p</i> = 0.61
Inpatient Mortalities, n (%)	297 (18.02)	253 (18.73)	

4.3. Current State Assessment of RBC Usage

The percentage of RBC units in individual clinical service lines compared to total hospital wide RBC units was calculated as a baseline analysis for the pre-intervention period (Oct. 2012 to Sep. 2013) 2013 (Figure 12). During the pre-intervention period 4910 RBC unit were transfused. Hospital Medicine represented 34.09 % (1,674 Units) of RBC usage, followed by Cardiothoracic Surgery 12.53 % (615 Units), General Surgery 9.84% (483 Units), Hematology and Oncology 9.41 (462 Units), and Pulmonary Medicine 8.76% (430 Units). The five clinical specialties accounted for 74.62 % of the hospitals total RBC use. In this study the specialty is defined as the physician in charge of ordering the RBC transfusion.

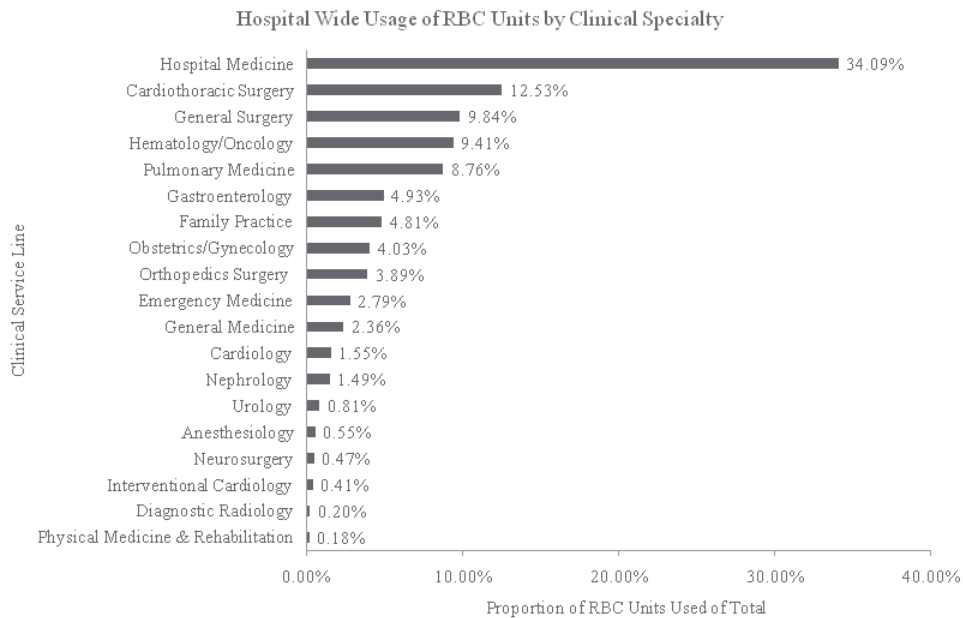


Figure 12 - Hospital wide usage of RBC units by clinical specialties.

Following AABB guidelines for PBM⁴⁸⁹ as a starting point, annual, and later quarterly, data on the overall RBC usage adjusted per 1000 patients was collated. The collated data provided a mechanism for benchmarking the hospital against itself and in the future against similar hospitals with a similar patient mix. Blood component usage data was collated by clinical service line (e.g. internal medicine, hospitalists, hematology/oncology, cardiothoracic surgery, orthopedic surgery) and even more specifically by physician group and individual healthcare provider which allowed focusing the efforts on identifying clinical service lines that utilized the most blood products and thus targeting the areas where education and change would have the greatest impact. (Figure 13) shows RBC transfusion per 1000 patient days by clinical service line.

Clinical specialties with the highest yield of RBC transfusion per 1000 patient days included: Hospital Medicine with 21.73, followed by Cardiothoracic Surgery with 7.98, General Surgery with 6.27, Hematology and Oncology 6.00, and Pulmonary Medicine with 5.58 RBC units transfused per 1000 patient days.

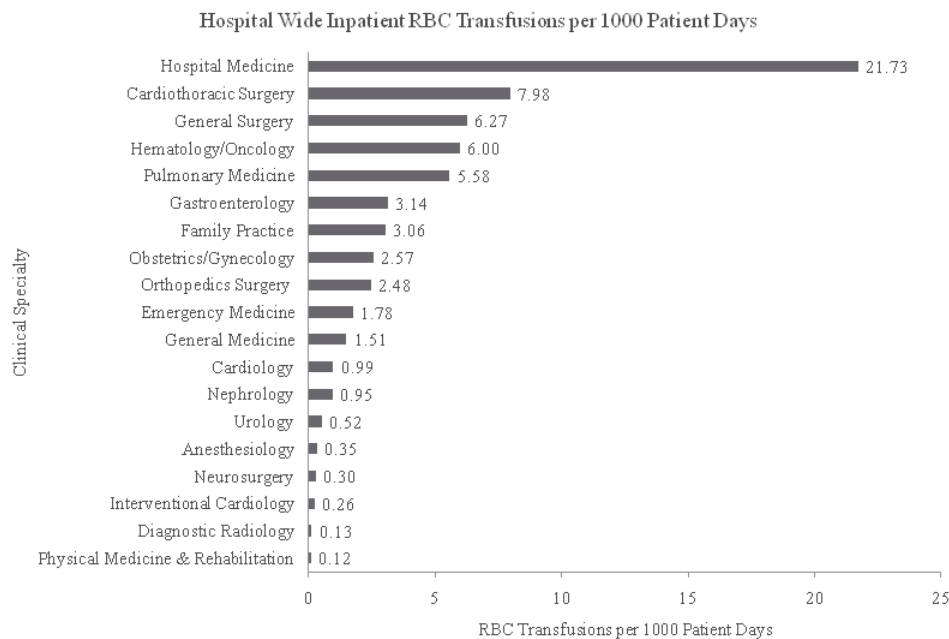


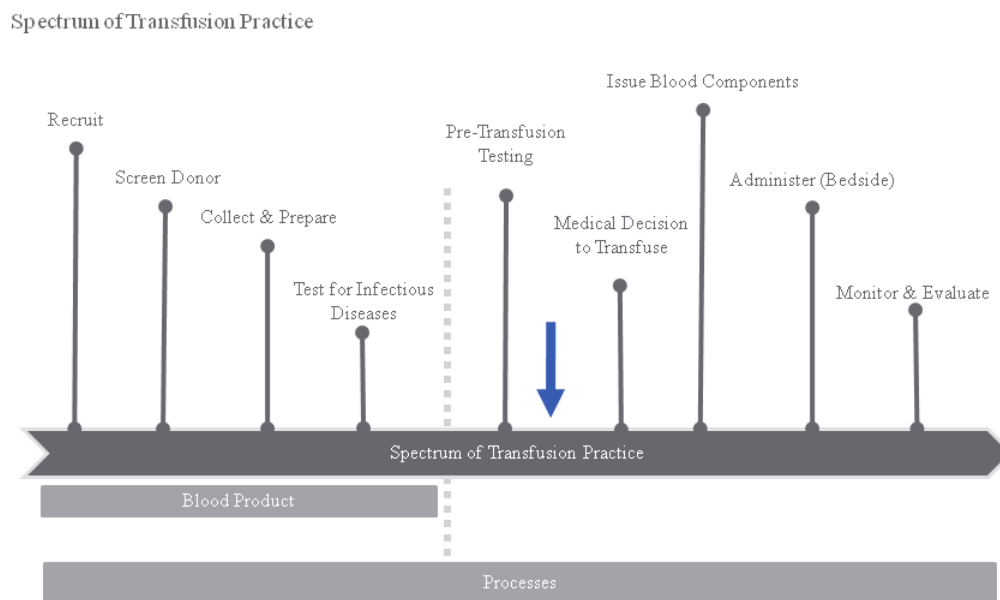
Figure 13 – Hospital-wide inpatient RBC transfusions per 1000 patient days.

4.4. The Impact of the Model on Hospitalists Transfusion Practice

Figure 14 is adapted from Dzik, W. Transfusion 2003; 43 (9):1190-1199. The figure represents the spectrum of activities and processes involved in transfusion of blood component(s). The overarching aim of this study was to implement restrictive transfusion strategies among hospitalists, using evidence-based guidelines, data analytics, reporting, meaningful presentation

of information, and focused education to drive appropriate decision making and interventions prior to formulating the decision to transfuse and prior to issuing of blood component(s). The arrow on Figure 14 represents the point on the transfusion spectrum where this study aims to influence the hospitalist's decision of whether to transfuse or not and how much.

Figure 14. Represents the spectrum of activities and processes involved in transfusion of blood or blood components (adapted from Dzik, W. Transfusion 2003;43 (9):1190-1199). The arrow shows the stage in the process at which the framework was employed to influence physicians' transfusion decisions.



Dzik, W. Transfusion 2003;43(9):1190-1199

Figure 14 - Represents the spectrum of activities and processes involved in transfusion of blood or blood components.

4.4.1. Changes in RBC Transfusions 1000 Patient Days

Figure 15 and 16 represents changes in inpatient RBC transfusions per 1000 patient days by hospitalists, comparing pre and post intervention periods. The dotted line identifies the separation between the Pre-Intervention and Post-Intervention time periods. Comparison of quarterly percent difference of Hospitalists' RBC transfusion activity per 1000 patient days showed a significant decline of 26.23% ($p < 0.01$), when comparing the Post-Intervention with that of Pre-Intervention periods. The average inpatient RBC transfusion per 1000 patient day during pre-intervention (Oct. 2012 to Sep. 2013) was 21.67 ± 2.29 compared to 15.69 ± 1.91 during post-intervention time period (Oct. 2013 – Sep. 2014).

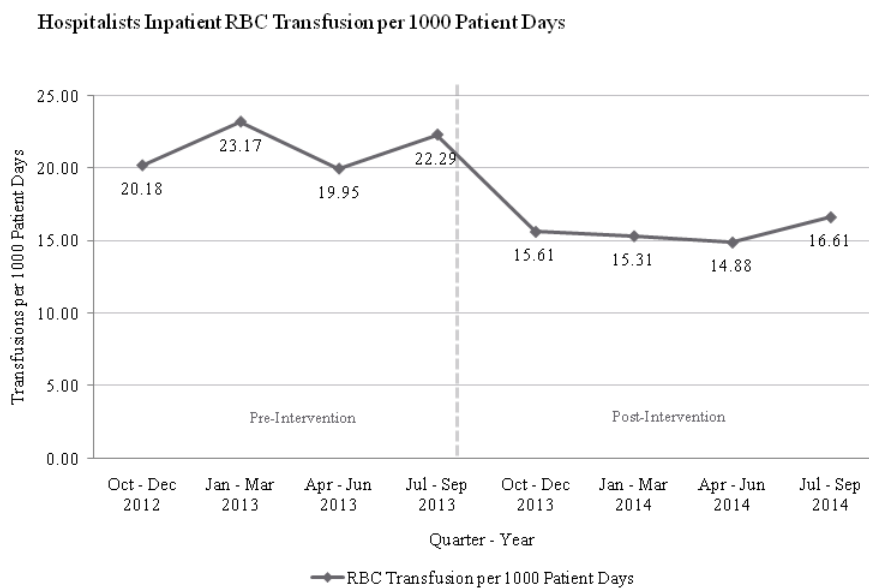


Figure 15 - Trend in Inpatient RBC transfusions per 1000 patient days among hospitalists.

Figure 16 represents quarterly changes in inpatient RBC transfusions per 1000 patient days by hospitalists and interventions that took place during pre and post intervention periods. The diamond end dotted line indicates circulation of newsletters (Appendix C) on the latest evidence on restrictive RBC transfusion approaches and a newsletter on one vs. two unit RBC ordering practice highlighting the following factors:

- Recommended a restrictive transfusion strategy with a transfusion threshold of hemoglobin level of 7 g/dL, or 8 g/dL for patients with cardiac conditions.
- Recommended orders of single-unit RBC transfusions for non-bleeding stable medical patients with a restrictive pre-transfusion Hgb trigger.
- Recommended post-transfusion reassessment for determination of patients need for subsequent transfusion

The solid line indicates continuing medical education on pillars of PBM (Appendix C). The green and blue arrows represent distribution of physician performance measure unblinded reports (created using InSight data analytics and reporting software) to the department heads for different clinical service lines and reports to individual hospitalists using a blinded comparison approach to their peers. The (Figure 16) represents quarterly changes in inpatient RBC transfusions per 1000 patient days by hospitalists and interventions that took place during pre and post intervention periods and timing of continuing medical education and reporting.

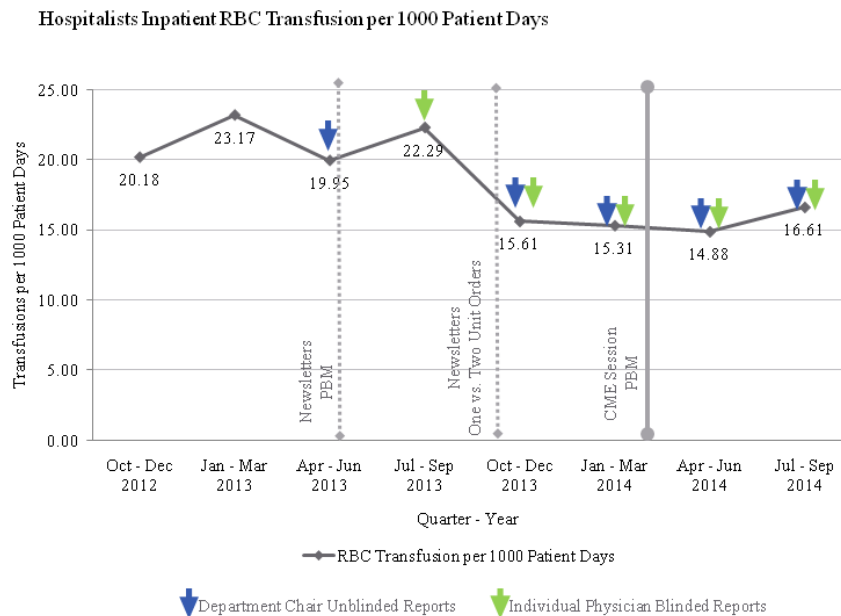


Figure 16 - Trend in Inpatient RBC transfusions per 1000 patient days among hospitalists and representation of the interventions.

4.4.2. Change in Transfusion Medicine Practice

Performance of individual physicians and the capability to assess that performance are increasingly the key drivers for improving the quality and efficiency with which health care is delivered. Expanding the capabilities to measure, report, and improve physician performance is among key initiatives that could be employed by wide variety of stakeholders (physician group, quality improvement team, etc.) in the hospital. This study reported performance information to individual physicians that followed objectives outlined in evidence-based transfusion guidelines (performance standard) and PBM newsletters highlighting three key areas including:

- Transfusion threshold of hemoglobin level of 7 g/dL, or 8 g/dL for patients with cardiac conditions;

- Orders of single-unit RBC transfusions for non-bleeding stable medical patients with a restrictive pre-transfusion Hgb trigger;
- Post-transfusion reassessment for determination of patients need for subsequent transfusion.

The underlying goal was to make physicians aware of their performance based on the evidence-based guidelines and to encourage improvement in specific aspects indicated above. Since the implementation of the evidence-based transfusion medicine framework, change was observed among hospitalists' transfusion practices.

4.4.3. Change in RBC Unit Orders

Figure 17 Comparison of pre – intervention (Oct 2012 – Sep 2013) orders (n = 1093) and post – intervention (Oct 2013 – Sep2014) orders (n = 800) showed a significant change in overall RBC ordering practice $\chi^2 (2, N = 1893) = 49.07, p < 0.01$; analysis of one vs. two unit RBC orders also showed a significant change in $\chi^2 (1, N = 1847) = 43.90, p < 0.01$. The percent of one-unit orders to total orders increased by 31.7%, and the percent of two-unit orders to total orders decreased by 30.9%. The green and blue arrows represent distribution of physician performance measure unblinded reports (created using InSight data analytics and reporting software) to the hospitalists' department head and reports to individual hospitalists using a blinded comparison approach to their peers.

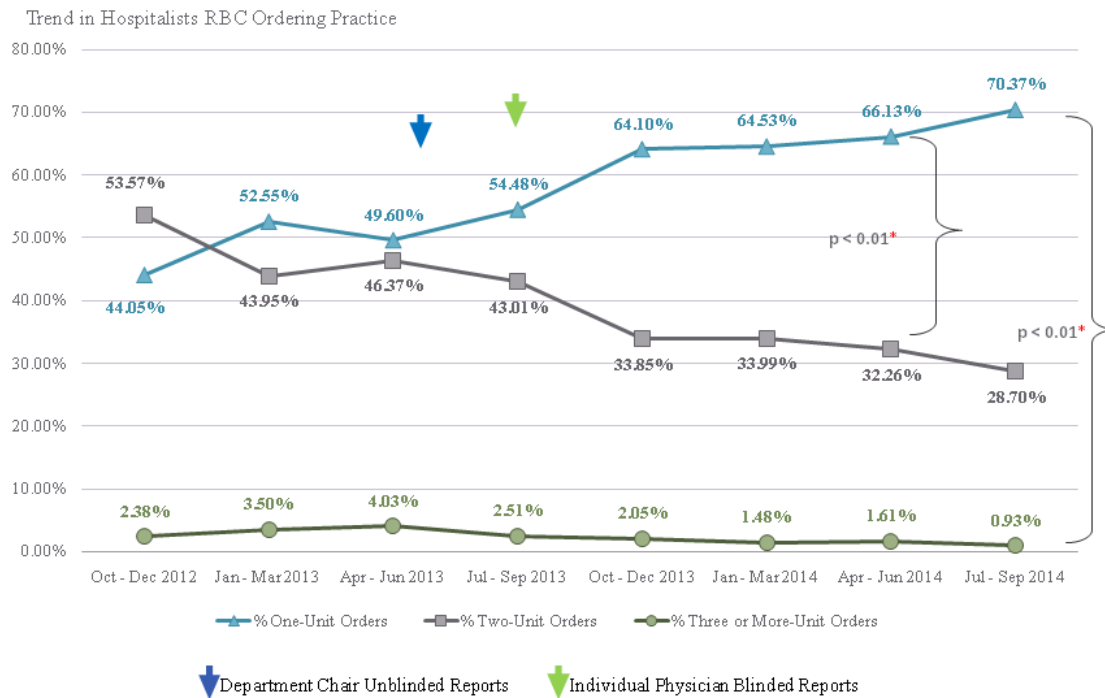


Figure 17 - Trend in hospitalists RBC unit ordering practice.

4.4.4. Change in Pre-Transfusion Hemoglobin Threshold

Figure 18, 19 represents analysis performed on one-unit and two-unit orders to determine whether there was a change in the transfusion threshold of hemoglobin level based on the performance standard. One-unit orders with pre-order Hgb values ≤ 7 and > 7 g/dL showed a significant shift towards a lower pre-transfusion Hgb trigger when the pre- and post-intervention periods were compared using a Chi-Square test $X^2(1, N = 849) = 4.60, p = 0.032$. Analysis of the mean pre-transfusion Hgb for one-unit orders during the pre-intervention period was 8.0 g/dL

(SD =0.71); the pre-transfusion Hgb trigger lowered to 7.7 g/dL (SD = 0.69) during the post-intervention period. Two-unit orders with pre-order Hgb values ≤ 7 and > 7 g/dL showed no significant change towards a lower pre-transfusion Hgb trigger when the pre and post periods were compared using a Chi-Square analysis $X^2 (1, N = 701) = 3.52, p = 0.06$. Analysis of the mean pre-transfusion Hgb for two-unit orders during the pre-intervention period was 7.5 g/dL (SD =0.80); the pre-transfusion Hgb trigger lowered to 7.4 g/dL (SD = 0.90) during the post-intervention period with no statistical significance. Although results are statistically not significant the trend is moving towards lower pre order Hgb trigger (Hgb values ≤ 7 g/dL (21.38% to 27.73%) and > 7 g/dL (78.62% to 72.27%) when compared pre to post intervention periods. Figure 18 and 19 represent the observed changes in pre-transfusion Hgb (g/dL) threshold.

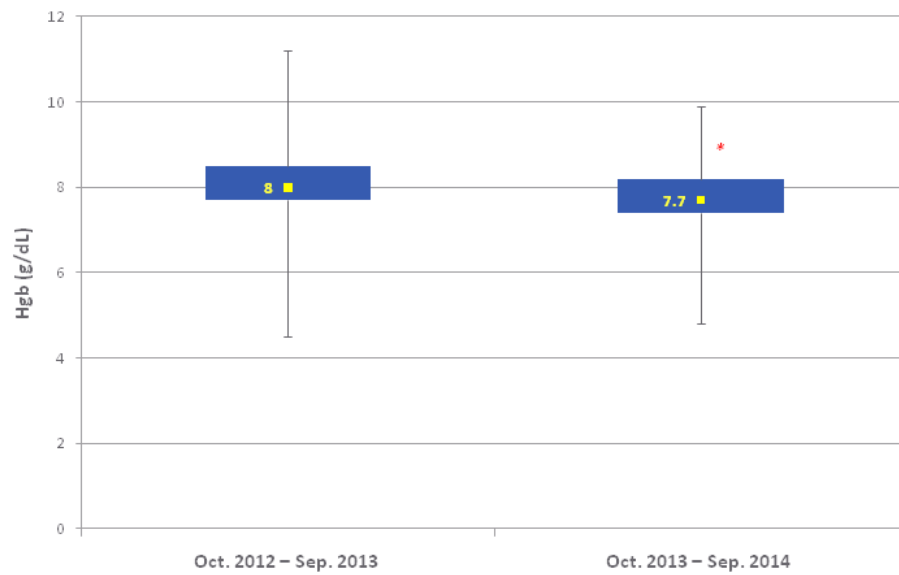


Figure 18 - Comparison of pre-order Hgb (g/dL) trigger for one-unit RBC transfusion orders among hospitalists.

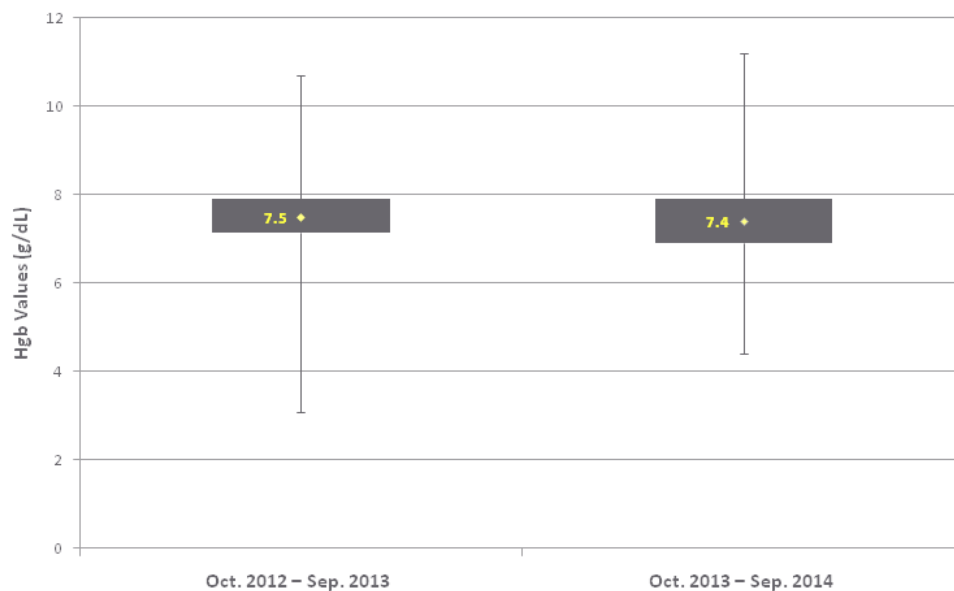


Figure 19 - Comparison of pre-order Hgb (g/dL) trigger for two-unit RBC transfusion orders among hospitalists.

4.4.5. Change in Post-Transfusion Assessment

Post-transfusion assessment of the effect of the RBC transfusion, specifically the increment in hemoglobin and hematocrit, is important. Blood specimen were collected as ordered by the hospitalists, however, timing of the phlebotomy may vary depending on the clinical condition of patient. Post-transfusion reassessment was quantified by examining the post-transfusion Hgb testing. Figure 20 for one-unit orders with pre-order Hgb value ≤ 7 ; Chi- Square analysis of the post-transfusion reassessment rate showed a significant change during post-intervention period

(X^2 (1, N = 90) = 12.52, $p < 0.01$). The odds ratio analysis showed the odds of post-transfusion Hgb reassessment were 5.41 times greater during post-intervention period. The same analysis was conducted for one-unit orders with pre-order Hgb value > 7 . The post-transfusion reassessment rate showed no change X^2 (1, N = 759) = 0.04, $p = 0.831$, however the reassessment rate after transfusion of one unit with pre-transfusion Hgb >7 g/dL remained steady during pre and post intervention periods with 84.91 and 85.52 percent respectively. The same analysis was performed for two-unit orders. For two-unit orders with pre-order Hgb value ≤ 7 ; Chi-Square analysis of the post-transfusion reassessment rate showed no significant statistical change X^2 (1, N = 165) = 0.17, $p = 0.674$. The rate of post transfusion reassessment after transfusion of two unit RBC orders remained steady during pre and post intervention periods with 93.94 and 94.45 percent respectively. The same analysis was conducted for two-unit orders with pre-order Hgb value > 7 ; the post-transfusion reassessment rate did not show a change X^2 (1, N = 530) = 2.49, $p = 0.11$. The rate of post-transfusion reassessment after transfusion of one unit RBC order with pre-transfusion Hgb >7 g/dL also remained steady during pre and post intervention periods with 98.90 and 96.99 percent respectively. The analysis showed no significant difference for post-transfusion reassessment Hgb testing because the rate of testing was already close to the maximum.

Post-Transfusion Reassessment of One-Unit Orders

Post RBC Order Reassessment with Pre-Order Hgb ≤ 7.0 g/dL				Post RBC Order Reassessment with Pre-Order Hgb > 7.0 g/dL			
Reassessment	Oct. 2013 – Sep. 2014	Oct. 2013 – Sep. 2014	Total	Reassessment	Oct. 2013 – Sep. 2014	Oct. 2013 – Sep. 2014	Total
Yes-Post order Hgb	17 (48.57%)	46 (83.64%)	63	Yes-Post order Hgb	328 (84.91%)	319 (85.52%)	647
No-Post order Hgb	18 (51.43%)	9 (16.36%)	27	No-Post order Hgb	58 (15.3%)	54 (14.48%)	112
Total	35	55	90	Total	386	373	759
Chi-Value	12.52			Chi-Value	0.0454		
p-Value	0.0004			p-Value	0.8312		

Post-Transfusion Reassessment of Two-Unit Orders

Post RBC Order Reassessment with Pre-Order Hgb ≤ 7.0 g/dL				Post RBC Order Reassessment with Pre-Order Hgb > 7.0 g/dL			
Reassessment	Oct. 2013 – Sep. 2014	Oct. 2013 – Sep. 2014	Total	Reassessment	Oct. 2013 – Sep. 2014	Oct. 2013 – Sep. 2014	Total
Yes-Post order Hgb	93 (93.94%)	63 (94.45%)	156	Yes-Post order Hgb	360 (98.90%)	161 (96.99%)	521
No-Post order Hgb	6 (6.06%)	3 (4.55%)	9	No-Post order Hgb	4 (1.10%)	5 (3.01%)	9
Total	99	66	165	Total	364	166	530
Chi-Value	0.1763			Chi-Value	2.4998		
p-Value	0.674588			p-Value	0.113862		

Figure 20 - Post-transfusion Hgb (g/dL) reassessment of one-unit and two-unit orders.

4.5. Economic Impact of the Change in Practice

4.5.1. RBC Transfusion Cost Breakdown

The cost model included product acquisition cost, and direct and indirect overhead costs. Direct overhead costs included elements such as blood bank staff (manager, laboratory, technician, etc.), related overhead costs for the blood bank, laboratory, nursing staff, and pathologist. Indirect overhead costs included three major process steps such as patient testing, pre-transfusion processes, and administering and monitoring transfusions. The national average blood product acquisition cost of $\$210.74 \pm 37.9$ was used based on the latest hospital-based blood banks and transfusion services 2011 survey¹³³. This cost did not include wasted RBC units and additional

services such as irradiating, washing, or warming of RBC units. Product acquisition cost contributed 33.19 % of the total cost of transfusion. The evaluation of direct overhead cost contributed a small percentage (8.91 %) of the overall blood-related costs; the indirect cost contributed the highest proportion of total transfusion cost of 57.90 %. Using the cost model, the total cost per RBC unit transfusion was determined to be \$ 634.97 ± 36.76 (Mean, SD). Using the cost model, an estimated 33.19 % (210.74 ± 37.9) of the total cost of transfusion was associated with the product acquisition cost and the remaining 66.81 % (424.23) was attributed to direct and indirect overhead cost (Figure 21.).

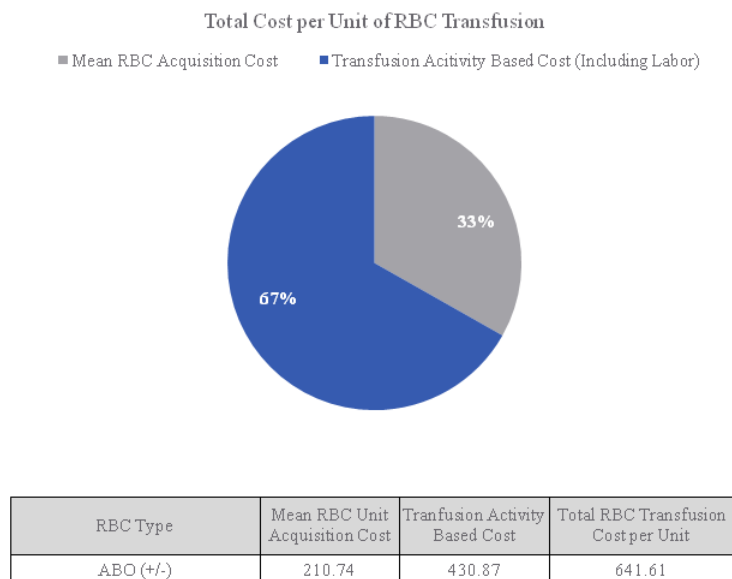


Figure 21 - Total cost breakdown per RBC unit transfusion.

4.5.2. Cost Analysis RBC Orders among Hospitalist and Non-Hospitalists

Based on the above cost estimates, the total cost of inpatient RBC transfusions among hospitalists and non-hospitalists during pre and post intervention periods was compared using the RBC unit acquisition cost and RBC transfusion activity-based cost. An independent sample t-test was conducted to compare unit cost of RBC transfusions among hospitalists (1675 to 1085 issued units) and non-hospitalists (3184 to 3005 issued units) during pre and post intervention periods. The cost analysis of RBC orders by hospitalists during the post-intervention time period showed a significant 27.49 percent decrease in cost per unit of RBC transfusion per 1000 Patient Days when compared the post-intervention period ($M = \$3,296.95$, $SD = 397.39$), with the pre-intervention period ($M = \$4,547.08$, $SD = 485.46$), $p < 0.01$. The same analysis was performed for non-hospitalists. The comparison of the post intervention period ($M = \$9,151.80$, $SD = 1,542.01$) with the pre-intervention period ($M = \$8,673.77$, $SD = 1,211.53$), $p = 0.42$ showed no statistical change in cost of RBC utilization among non-hospitalists.

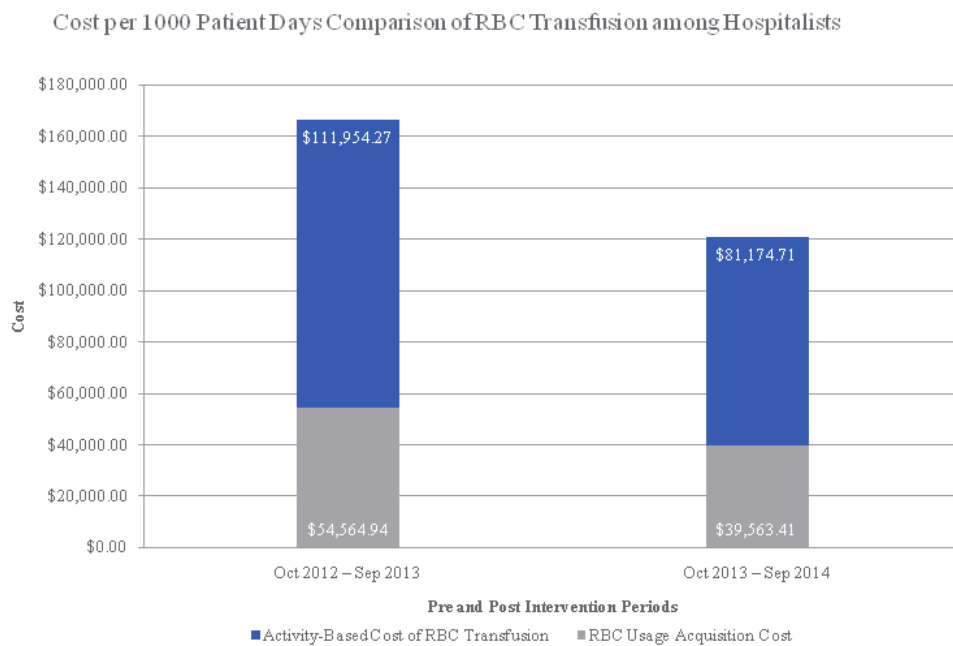


Figure 22 - Comparison of total cost per 1000 patient days of RBC transfusion (cost per unit and activity-based cost) during pre- and post-intervention periods among hospitalist.

Cost per 1000 Patient Days Comparison of RBC Transfusion among Non-Hospitalists

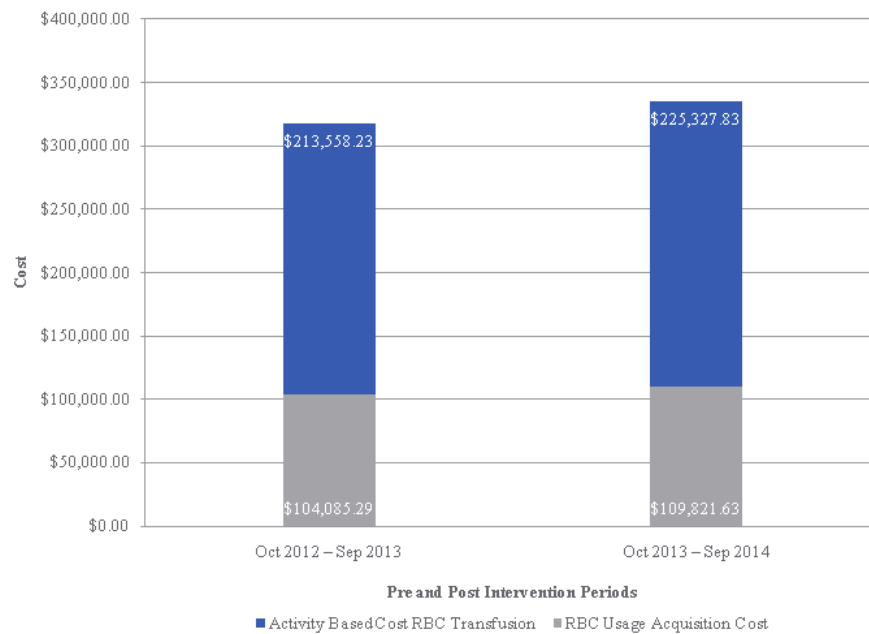


Figure 23 - Comparison of total cost per 1000 patient days of RBC transfusion (cost per unit and activity-based cost) during pre- and post-intervention periods among non-hospitalist.

4.5.3. Trend Cost Analysis of Hospitalists Practice

The cost analysis breakdown of inpatient RBC orders among hospitalists showed a significant overall decrease of 27 percent ($p < 0.01$) in cost of RBC transfusion per 1000 patient days as a result of the decline in the number of orders. Figure 24 represents the trend in quarter-year decline in the cost of RBC orders per 1000 patient days including one, two, and three or more unit RBC orders.

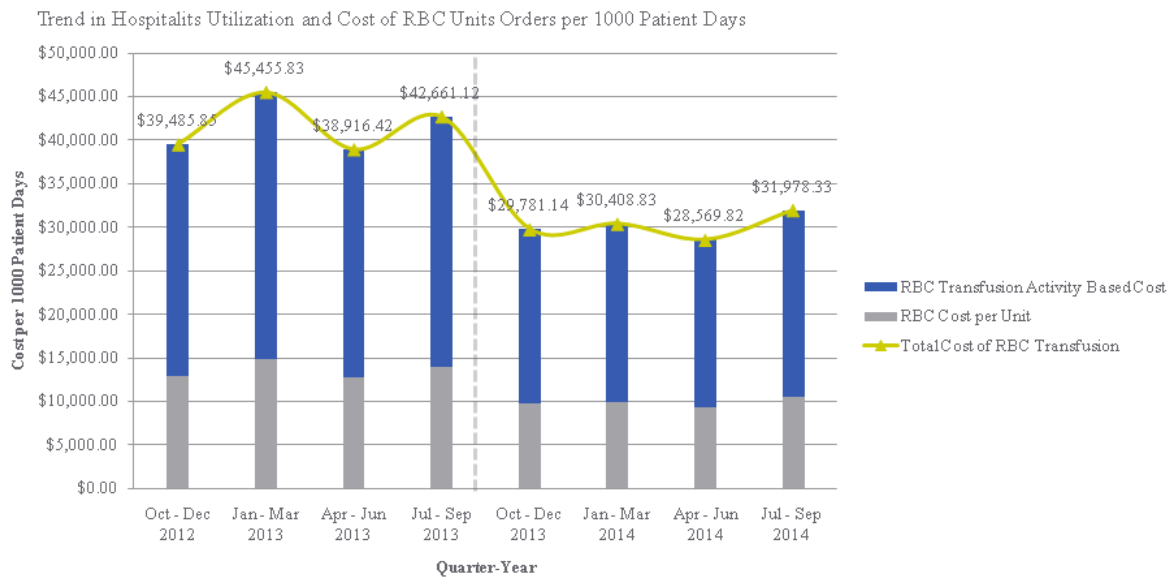


Figure 24 - Quarterly trend in hospitalist utilization and total cost of RBC transfusion per 1000 patient days.

Chapter 5: Discussion

Rising healthcare costs and declining quality of care have heightened the need to identify and implement new strategies to address shortcomings in the United States healthcare system. This study focuses on promoting evidence-based medical practice and leveraging healthcare data to improve quality of care, outcomes, and control costs. The study demonstrates the effectiveness of a framework that bridges the gaps that exist between data, knowledge, and practice in a healthcare setting through the use of evidence-based guidelines, enhanced contextualized data-driven reports, analytics and education focused on current evidence.

This study focuses on transfusion medicine. Transfusion is one of the top ten coded hospital procedures in the United States. Unfortunately, the costs of transfusion are underestimated and the benefits overestimated. The particular aim of the study was to reduce practice inconsistencies in red blood cell transfusion among hospitalists in a large urban hospital using focused education, evidence-based guidelines, and reporting based on physician-specific data to drive appropriate decision-making prior to the decision to transfuse or prior to issuing the blood component, and data analytics to serve as a feedback mechanism to evaluate changes in behavior and practice. The study's integrated framework proved to be effective in encouraging evidence-based best practices and lowering costs.

This study sought to achieve an institutional shift to evidence-based transfusion medicine practice using a framework that took into account the administrative, cultural, clinical, and technical issues that make the implementation of an evidence-based program and utilization of

healthcare data so challenging. What follows is a discussion of the components of the framework that proved to be effective in addressing the issues associated with the study's deployment of healthcare data in the shift to evidence-based medicine.

5.1. Administrative Issues

5.1.1. Strategic Focus

There were challenges related to the introduction of the strategic and organizational changes that were needed to promote new programs and that would encourage the uptake and use of new knowledge. This required clear top down direction, administrative support and action, collaboration, re-working of resources and priorities, resource dedication to goals that were specific to evidence-based practice, and commitment to dedicating the skills and technologies needed to measure changes, track and evaluate programs^{77,279,282,490-494}. High level support and involvement were needed to meet the ambitious goal of encouraging hospitalists to move from a culture of delivering care based on tradition, intuition, and authority, to a system in which decisions were guided and justified through education, awareness of the best available evidence, and measure of performance based on physicians' specific practice data.

5.1.2. Resource Commitment

Administrative buy-in and support at the highest levels of the organization was essential for the successful implementation of this hospital-wide, cross-departmental, evidence-based patient blood management program with its heavy reliance on a performance management system, data analytics, and reporting. While the healthcare organization may have already recognized the

importance of the use of data, it was critical that they make the resource commitment to address issues related to the development of the components of the performance management system including: data location (diverse and disparate information ecosystem); data definitions (inconsistencies in data definitions subjected based on the source system); data structure (inconsistency in data capture structured vs non-structured); data complexity (presence of numerous identical parts in amalgam of individual systems) , and staff allocation (with appropriate skills and time) .

5.1.3. Coordination

It was important that structures be put into place that insured ongoing communication and coordination between the hospital and BloodCenter of Wisconsin and as well as among all the involved individuals and departments within the hospital. The Blood Utilization Governance Committee was established as a way to develop and sustain broad organizational support. The overarching goal of this committee was to create a culture of accountability among physicians who practiced transfusion therapy. The committee consisted of hospital executives, administrative, and clinical champions including the Vice President of Medical Affairs, the Vice President of Laboratory, the Laboratory Medical Director, the Blood Bank Supervisor, a hospitalist physician champion, and transfusion safety nurse champion. The Blood Utilization Governance Committee established sub-committees that assigned specific responsibilities to various working groups.

5.1.4. Ongoing Feedback

Developing an analytics framework to provide a continuous feedback mechanism contributed to the overall success of the program and provided the tools to inform the executives and administration on progress. The framework served to provide a feedback mechanism relative to the strategic objectives, aggregate data obtained from the performance management system, and the effectiveness of the education that healthcare providers received. The analytics framework, through quantification and long-term reassessment of trends, facilitated a deeper understanding of the clinical changes that the hospitalists made in their transfusion practice as a result of informed decision-making. In addition, it enabled evaluation of changes directly impacted by the program, identified new areas for improvement, and helped avoid unintended consequences and outcomes. A set of high-level indicators were used to provide feedback to the Blood Utilization Governance Committee for determination and any needed adjustment to goals, objectives, priorities and strategies. The operational indicators included: hospital-wide trends of blood product inventory and rate of wastage; total number of blood products transfused by product type, patient type, and by nursing unit; and measures of blood product ordered by various clinical specialties. In addition to reporting the operational indicators, a set of nationally accepted benchmark indicators were constructed and used to inform the Blood Utilization Governance Committee with regard to the hospital's current trends on patient transfusions and blood product utilization. These benchmark indicators included: measure of inpatient and outpatient transfusions per 1000 patient days based on patient census, and measures of admitted patients who received transfusions by a specific blood product.

5.2. Cultural Issues

5.2.1. Behavioral Change

An informative rather than punitive approach was employed with regard to implementation of the evidence-based PBM program in order for the message to be well-received among physicians and other healthcare providers. Strategies included physician education promoting conservative RBC transfusion strategies through continuing medical education courses, newsletters, and posters and quarterly reports to department chairs and to individual hospitalists highlighting RBC ordering practices of the physicians and other healthcare providers. The department reports on physicians' transfusion practice was unblinded for the review of the department chair. The individual physician report was blinded using a system-generated identifier for each physician to allow comparison of individual physicians to their peers. Individual physicians responded differently making varying levels of intervention (e.g. education, peer-to-peer discussions, performance reports, letters from the department head and performance review consequences) a valuable framework component.

5.2.2. Tradition, Intuition and Authority

Studies have shown each unit of allogeneic RBC increases the rate of nosocomial infection by fifty percent; transfusion of patients with two units of RBC can highly increase the rate of hospital acquired infections^{409,495-498}. Thus the common practice to “automatically place two-unit RBC orders makes no sense from a resource consumption or patient safety standpoint⁴⁹⁸”. It has been more than a decade since the publication of the landmark study “Transfusion

Requirements in Critical Care (TRICC) trial”¹⁴⁸ and many others studies^{140,142,149,155,182-184} supporting the restriction of RBC transfusions for patients¹⁸⁵. Since then, there have been some reports indicating improvements in transfusion practices, mostly with regard to reduced hemoglobin thresholds at which patients are transfused¹⁸⁶⁻¹⁸⁸. Nonetheless, the overall use of allogeneic RBC transfusions in clinical practice remains relatively high and still varies widely among many centers and practitioners^{185,189-191}. One underlying issue is that many physicians were trained before transfusion research and evidence were available regarding transfusions. Historically, some physicians have been taught liberal transfusion practice and to follow the maxim “if you are going to transfuse, why not give two”^{15,194,195}. Now, however, numerous research studies have examined RBC^{148,149,155,162,182,183,196,197} and platelet use^{27,198-202}. Nonetheless, many clinicians are slow to change¹⁵, and some are even skeptical without seeing hard evidence, such as individualized data-driven reports, information on latest research evidence in practice, reports on their individual practice and the practice of their peers. The framework developed for this study was designed to promote a move beyond tradition, intuition and authority-based practice to practice informed by education focused on current evidence, evidence-based guidelines, and enhanced contextualized data-driven reports.

5.2.3. Transfusion Medicine Expertise

The practice of transfusion medicine extends across multiple specialties and covers diverse clinical and laboratory services. It requires specialized subject matter expertise and an understanding of the intricacies, underlying complexities and latest transfusion medicine best-practice evidence. In transfusion medicine, as in other areas of medical practice, there is a gap

between the latest knowledge and current physician practice. As commonly as transfusions occur in the United States, one may assume that physicians practice transfusion medicine based on strict standard guidelines. However, the efficacy of blood transfusion is poorly understood among practicing physicians¹³⁹⁻¹⁴³. Partnering with BloodCenter of Wisconsin to provide access to best-practice expertise and the latest research findings was essential in off-setting any lack of transfusion medicine expertise among the hospitalists. The committee used the performance standard, *BloodCenter of Wisconsin 2011 Adult Blood Utilization Review Guidelines*, to establish key objectives and relied on BCW expertise throughout the process.

5.4. Clinical Issues

5.4.1. Relevant Clinical Information and Evidence

Challenges in a shift from authority-based medicine to evidence-based medicine include the lack of relevant clinical information, inadequate time and the inability of physicians to review and interpret available evidence and translate new knowledge into clinical practice⁴. Offering continuing medical education courses, training, and distributing educational materials on conservative transfusion therapy strategies (including lower pre-transfusion Hgb trigger and transfusion of a single RBC unit followed by patient reassessment for determination of additional interventions) and appropriate and inappropriate use of blood products (including adverse effects of blood products, misuse and overuse of blood components that increases the risk of morbidity in patients, cost and financial resources associated with unwarranted blood transfusions) were important parts of the strategy to change or enhance clinical practice. In addition to the courses,

training sessions and educational materials, physicians were provided access to EndNote to allow them to delve further into relevant information.

5.4.2. Performance Management System

Use of a performance management system improved transfusion medicine practice through the synthesis and utilization of scientific evidence and the more rigorous use of data analytics to provide meaningful information and to guide daily activities of physicians by creating a culture of accountability. In addition it provided a feedback mechanism for assessment and reassessment of change and the evaluation of the impact of strategic decisions. Developing and using a performance management system served to identify, select objectives and set goals, increase awareness on the latest evidence to promote conservative strategies on transfusion therapies and to create a culture of accountability by tracking physicians' transfusion criteria in accordance with the latest evidence. The performance management system aimed to optimize transfusion decision-making, reduce inappropriate transfusions, improve patient outcomes, reduce cost, and preserve a scarce resource through consolidation of measures to monitor and manage physicians' performance according to set of indicators and key performance indicators.

5.4.3. Dynamism in Medicine

Another aspect that adds to the complexity of evidence-based practice is its dynamic nature. As research advances, medical knowledge is enriched; thus clinical practice and healthcare technology evolve and new best-practices arise with new definitions of terms, new criteria, and

different approaches. As a result, evidence-based best-practices continue to be redefined in an unpredictable manner and with it clinical approaches, regulatory, and reporting requirements change. It was for this reason that highly specialized subject matter expertise, flexible and scalable performance management systems, and a feedback mechanisms were built into the framework.

5.5. Technical Issues

5.5.1. Data Silos

A central database and the performance management system architecture were fundamental to the patient blood management program. The linkage of transfusion-related data across the hospital's disparate source systems was an essential first step to monitor compliance with transfusion best-practice guidelines across various clinical service lines. A patient blood management database was established at BloodCenter of Wisconsin to centralize data from the disparate source systems from within the hospital and as a means to evaluate the hospital's transfusion practices both as a baseline before intervention (the implementation of transfusion medicine best practice program) and as an ongoing monitoring system. There were three critical components to the success of this implementation model including: 1) the ability to collect and use recent and precise data that could be processed into meaningful information to show where, how, by whom, and how much blood product was used within the hospital wards; 2) the ability to use the information gained from data in a continuous feedback mechanism to inform the strategic decision makers as a means to assist in the strategic level decision making process; and

3) the ability to use the clinical practice data to benchmark clinical performance and blood product utilization.

5.5.2. Data Determination

The method used to identify relevant and contextual data elements across the source systems included the involvement of the Blood Utilization Governance Committee in reviewing the organizational and departmental (i.e. clinical service lines) strategic goals and priorities; determining of target audiences aligning of patient blood management evidence-based guidelines to the strategic goals; identifying activities to track progress toward the established goals; linking the activities to a specific measure or group of measures; setting target and threshold for expected outcomes; and developing meaningful reports from the measures to inform on the outcome and progress. The approach facilitated construction of the performance management system through identification of relevant datasets and the correct source system for extraction of the data. For each department and the source system, characteristics of data and the quality of source system was determined. Based on the frequency of data capture, automated or semi-automated data feeds were scheduled to actively (depending on the specific processes and timeliness of data capture on a daily, weekly, or monthly intervals) transfer the data into the central repository for processing.

5.5.3. Data Linkage

The linkage of transfusion-related data across the hospital's disparate source systems was a fundamental first step in monitoring compliance with transfusion best-practice guidelines across clinical service lines. Using the study method, 99.15 percent of discharged inpatients were linked

to their transfusion events and clinical detail; 97.77 percent of physicians and other healthcare providers (including physician's assistants and nurse practitioners) were linked to their primary clinical specialty within the hospital. Thus 99.98 percent of inpatients who received at least one unit of blood products were linked to their transfusion event and clinical details, in addition to the issuing physician information. Once the linkage of patients to their clinical detail and providers was completed, the performance measures were used to track and trend healthcare providers' practice and blood product utilization across the hospital.

5.5.4. Data Transfer

The data feeds were transferred to the central repository via a secure file transfer (e.g. sFTP) connection. A unified metadata layer was defined; and data from the various source systems were mapped to enable contextual information. Data was stored in SQL database, where numerous views (virtual tables) were created to join the subset of data from various tables (populated from disparate information systems) with coded logics built-in for contextual view of data, and to limit exposure to the underlying data. The logics were coded in the views to link data on patient, provider, blood products and clinical details that were required to for individual measures in the performance management system. InSight (Lenexa, KS), an analytics and reporting software, was used for construction of the measure as part of the performance management system with dashboard and reporting capabilities for dynamic views of information. The reports from the performance measures were presented back to the hospital via a secure web-based portal which depicted blood product use, and physician ordering practice at multiple levels including by system, facility, cost center, clinical service line, and healthcare provider.

5.5.5. Information Reporting

Data analysis was regularly communicated throughout multiple levels of the healthcare organization including at healthcare system level, hospital level, clinical service line level, and physician level based on guidelines established by the Blood Utilization Governance Committee. Dashboards were tailored to meet the information requirements of administrative and clinical personnel.

5.6 Study Outcome

The Blood Utilization Governance Committee made the determination to target RBC utilization as the most frequently issued blood component (69.75% RBC, 22.73% FFP, 6.81% PL, and 0.72% CRYO), and hospitalists as the highest users of RBC units. The indicator measuring the percentage of RBC units in individual clinical service lines compared to total hospital wide RBC units was calculated as a baseline analysis for the pre-intervention period (Oct. 2012 to Sep. 2013). It showed hospitalists (34.09%) were the highest users of RBC units, followed by cardiothoracic surgery (12.563%), and general surgery (9.84%). The first five clinical specialties (e.g. Hospital Medicine, Cardiothoracic Surgery, General Surgery, Hematology/ Oncology and Pulmonary Medicine), accounted for 74.62 % of the hospitals total RBC use. Benchmark indicators showed an annual rate of RBC transfusions per 1000 patient days to be 62.95 and 21.67 across all clinical service lines and hospitalists respectively during pre-intervention period. The study focused on reducing the inconsistencies in practice of transfusion medicine, particularly in the transfusion of allogeneic RBC among Hospitalists in the hospital.

Retrospective analysis of hospitalists practice during pre (Oct. 2012 – Sep. 2013) and post (Oct. 2013 – Sep. 2014) intervention periods showed a 27.62 percent decline in inpatient RBC transfusion per 1000 patient days. Analysis of hospitalists ordering practice showed a significant change in number of one and two unit RBC orders. The rate of two-unit RBC orders significantly decreased by 30.88 percent ($p < 0.01$), while the rate of one-unit RBC orders significantly increased by 31.67 percent ($p < 0.01$).

More in-depth analysis was performed on one-unit and two-unit orders to determine whether there was a change in transfusion threshold of Hgb level based on the performance standard. Comparison of the mean Hgb threshold for one-unit orders during pre and post intervention periods (8.0 ± 0.71 to 7.7 ± 0.69 , $p < 0.01$) showed a significant shift towards lower pre-transfusion Hgb threshold. Although, the trend showed a positive shift toward lower Hgb threshold, hospitalists' decisions on transfusion triggers will require more interventions to further lower transfusion triggers (Hgb concentration of 7 g/dL or less for non-bleeding stable patients or 8 g/dL for patients with cardiac conditions). The same analysis was performed for two-unit orders and no statistically significant change was observed. Post-transfusion assessment of the effect of the RBC transfusion for assessment of incremental change in hemoglobin and hematocrit level was quantified by the rate of post-transfusion Hgb testing. For one-unit orders in patients with pre-order Hgb value ≤ 7 , the post transfusion assessment rate showed a significant increase of 35.06 percent ($p < 0.001$). The same analysis was performed for two-unit orders and no statistical significant change was observed. However, during the pre and post-intervention period the rate of post transfusion assessment after transfusion of two unit RBC order had remained steady with the average of $94.19 \% \pm 0.36$ in across the two time periods.

The post-intervention period showed a 35.24 percent ($p < 0.001$) reduction in the total number of RBC units issued by hospitalists. The reduction in the number of RBC unit transfusions had a significant financial impact, which had led to an annual saving of \$124,337 based on the price-per-unit (national average) of RBC acquisition alone during post intervention period. However, estimating cost of transfusion based on the price-per-unit acquisition cost has been criticized by the Cost of Blood Consensus Conference. Traditional cost models lack the complex pre-transfusion preparation and post transfusion steps, thus attributable cost per unit has been greatly underestimated¹³⁵. A recently developed cost model by the Cost of Blood Consensus Conference included activity-based costing, which comprehensively accounted for the cost of transfusion through analysis of technical, administrative, and clinical processes. Using the activity based cost model, the technical, administrative, and clinical processes that occurred sequentially and in parallel were mapped. Each process step that involved diverse personnel, capital, and consumable resources was multiplied by the usage frequencies. National average price per unit acquisition cost of RBC unit and the activity based cost analysis of a single unit RBC transfusion at the hospital were estimated to be \$ 210.74 \pm 37.9 and \$424.23 respectively. Total cost of a single unit RBC transfusion per patient was determined to be around \$634.97. Analysis of the reduction in hospitalist RBC transfusions using total cost RBC transfusion (price per unit acquisition cost and activity based cost) showed an annual saving of \$374,632 during post intervention period.

The effectiveness of the various educational and reporting interventions used during the study time period to influence prescribing behavior were evaluated. Although the report to the

department chair provided visibility to hospitalists' practices and allowed for an avenue of conversation, individual peer-comparison-blinded reports had the greatest impact in changing the practice of the hospitalists. Trends began to significantly shift when the individual hospitalists were able to view their practice information and compare themselves to their peers.

The study model empowered the hospital, through the Blood Utilization Governance Committee and the Transfusion Medicine Steering Committee to encourage hospitalists to move from a culture of delivering care based on tradition, intuition, and authority, to a system in which decisions were guided and justified by education, awareness of the best available evidence and specific data relative to performance-based measures. The model provided an effective way for hospitalists to avoid over-transfusion of their patients through the order of one RBC unit at a time in stable non-bleeding patients, and re-assessment of the patient prior to ordering additional RBC units. If a single unit increased the patients Hgb into 7 to 8 g/dL range, the needed symptomatic patient relief was achieved. Thus, the hospitalists were able to avoid over-transfusion, which would only increase the future risk of adverse outcomes to their patients. This approach facilitated a sense of accountability among hospitalists by holding them accountable for their decisions on a daily basis. The totality of all hospitalists being accountable for their decisions served to create accountability at individual, department, and organization level. . The success of the pilot program that was executed for this study has led to the expansion of the program to all of the healthcare system's other hospitals. .

A way to address unexplained differences in clinical practice requires evidence-based guidelines, identification and collection of contextual data from diverse and disparate source systems, development and use of a performance management system, analysis of healthcare providers' transfusion practice data, and meaningful presentation of information firmly coupled with topic-focused education to drive appropriate decision-making and interventions. In addition, the model requires a closed feedback mechanism to quantify and evaluate the changes in practice. Reporting on compliance to evidence-based guidelines and performance measures are foundational; the addition of an analytics framework as a feedback mechanism is essential to further evaluate changes related to implementation and adherence to an evidence-based program. The study demonstrated that focus on tight integration of the above elements can bridge the gap that exists between knowledge and practice, and thereby can alter behavior.

5.7. Study Limitations

5.7.1. Organizational Agreements

Legal agreement between the two organizations imposes a rigid boundary around the scope of the project, and resources. Additionally, limited opportunities for interactions with key stakeholders and practitioners confines opportunities and makes it difficult to test new ideas or hypotheses.

5.7.2. Software System

Historically, business intelligence and reporting consisted of pre-defined reports and data visualizations that centered on classic tables, pie charts, and bar charts. BI tools have evolved to contain advanced analytics and visualizations, which encourage business users to have a more active role in data analysis. *InSight™* is a metrics-based dashboarding software system that adheres to the out-dated business intelligence model. *InSight™* has limitations that preclude it from fulfilling the evolving needs of end-users.

- ETL / Data Warehouse Capabilities

InSight™ provides limited, non enterprise-level ETL capabilities and no true data warehouse functions. It most readily integrates with Microsoft databases and flat files, but does not easily integrate with other types of databases (i.e. Oracle) or any other data sources. The ETL processes are fragile and prone to failure which requires manual intervention on a regular basis.

- Scalability & Multi-Tenancy

InSight™ is not a scalable solution and does not support multi-tenancy. The study needs a single view of the data that spans multiple healthcare systems in order to inform performance within each hospital, create benchmarks for partner organizations, and to provide an internal view of program success. Due to its architecture, requires its own development and production databases, and application environment for every healthcare system.

- Rigid Metric Hierarchy

The metric implementation is rigid; the drill down paths are confining and do not allow users to apply multiple filters to the data set (i.e., select a service line AND a type of blood product.) The lack of flexibility requires multiple measures to be created for each hierarchy drill path.

- Visual Analysis

*InSight*TM contains very limited visual analysis capabilities. Users are unable to create the simplest visual representations such as clustered or stacked bar charts; this requires transfer of data to Excel for further graphical capabilities.

- Report Creation

The lack of presentation capabilities necessitates users to export most data into Excel to prepare the information for analysis or for presentation back to the healthcare systems.

The *Insight*TM does not create pixel perfect reports for electronic distribution or print.

- Dashboard

Dashboards are inflexible, and the configuration required to create and maintain them does not provide a sustainable model. The Flash player tool becomes overwhelmed with a large data set and it can take several minutes (3-4) to add a single row to a view.

- Ease of Use

The product is not positioned as a business user solution because complex SQL is needed to create views for reporting purposes.

- Data Discovery & Ad hoc Analytics

The product does not support data discovery capability or ad hoc analytics to enable system users to slice and dice data.

- Collaboration

*InSight*TM only supports file export, print, and email capabilities. There is no ability to notate or collaborate within the tool.

- System Integration

*InSight*TM does not provide the ability to embed its metrics into other websites.

References

1. Hofmann A, Ozawa S, Farrugia A, Farmer SL, Shander A. Economic considerations on transfusion medicine and patient blood management. *Best Pract Res Clin Anaesthesiol* 2013;27:59-68.
2. Gombotz H, Rehak PH, Shander A, Hofmann A. Blood use in elective surgery: the Austrian benchmark study. *Transfusion* 2007;47:1468-80.
3. Gerris J. The legacy of Archibald Cochrane: from authority based -towards evidence based medicine. *Facts Views Vis Obgyn* 2011;3:233-7.
4. Mamdani M, Ching A, Golden B, Melo M, Menzefricke U. Challenges to evidence-based prescribing in clinical practice. *Ann Pharmacother* 2008;42:704-7.
5. Groves P, Kayyali B, Knott D, Van Kuiken S. The Big Data Revolution in Healthcare. McKinsey & Company Center for U.S. Health System Reform Business Technology Office; 2013.
6. Heddle NM. Evidence-based decision making in transfusion medicine. *Vox Sang* 2006;91:214-20.
7. Grol R. Successes and Failures in the Implementation of Evidence-Based Guidelines for Clinical Practice. *Medical Care* 2001;46-54.
8. Bodenheimer T. The American health care system--the movement for improved quality in health care. *N Engl J Med* 1999;340:488-92.
9. Schuster MA, McGlynn EA, Brook RH. How good is the quality of health care in the United States? *Milbank Q* 1998;76:517-63, 09.
10. Mowatt G, Grimshaw JM, Davis DA, Mazmanian PE. Getting evidence into practice: the work of the Cochrane Effective Practice and Organization of care Group (EPOC). *J Contin Educ Health Prof* 2001;21:55-60.
11. Grol R, Grimshaw J. From best evidence to best practice: effective implementation of change in patients' care. *Lancet* 2003;362:1225-30.
12. Pfuntner AW, Lauren M., Stocks C. Most Frequent Procedures Performed in U.S. Hospitals, 2010: H.CUP Healthcare Cost and Utilization Project; 2013.
13. Pfuntner A, Wier LM, Stocks C. Most Frequent Procedures Performed in U.S. Hospitals, 2011: H.CUP Healthcare Cost and Utilization Project; 2013.

14. AABB. Patient Blood Management. Advancing Transfusion and Cellular Therapies Worldwide; 2015.
15. Cohn CS, Welbig J, Bowman R, Kammann S, Frey K, Zantek N. A data-driven approach to patient blood management. *Transfusion* 2014;54:316-22.
16. Hendrickson JE, Hillyer CD. Noninfectious serious hazards of transfusion. *Anesth Analg* 2009;108:759-69.
17. Gilliss BM, Looney MR, Gropper MA. Reducing noninfectious risks of blood transfusion. *Anesthesiology* 2011;115:635-49.
18. Vamvakas EC, Blajchman MA. Transfusion-related mortality: the ongoing risks of allogeneic blood transfusion and the available strategies for their prevention. *Blood* 2009;113:3406-17.
19. Vamvakas EC, Blajchman MA. Blood still kills: six strategies to further reduce allogeneic blood transfusion-related mortality. *Transfus Med Rev* 2010;24:77-124.
20. Chatterjee S, Wetterslev J, Sharma A, Lichstein E, Mukherjee D. Association of blood transfusion with increased mortality in myocardial infarction: a meta-analysis and diversity-adjusted study sequential analysis. *JAMA Intern Med* 2013;173:132-9.
21. Shander A, Hofmann A, Ozawa S, Theusinger OM, Gombotz H, Spahn DR. Activity-based costs of blood transfusions in surgical patients at four hospitals. *Transfusion* 2010;50:753-65.
22. Grazzini G. Clinical appropriateness of blood component transfusion: regulatory requirements and standards set by the Scientific Society in Italy. *Blood Transfus* 2008;6:186-90.
23. World Health Organization. Total expenditure on health as a percentage of gross domestic product (US\$): World Health Organization; 2012.
24. Min H. Healthcare Supply Chain Management: Basic Concepts and Principles. Business Expert Press; 2014.
25. de Rugy V. US Health Care Spending More Than Twice the Average for Developed Countries. Mercatus Center at George Mason University 2013.
26. Advisers TCoE. The Economic Case for Health Care Reform. The White House 2009.
27. Davis K, Schoen C, Stremikis K. Mirror, Mirror on the Wall: How the Performance of the U.S. Health Care System Compares Internationally, 2010 Update. The Commonwealth Fund 2010.

28. Moses H, Matheson DH, Dorsey ER, George BP, Sadoff D, Yoshimura S. The anatomy of health care in the United States. *JAMA* 2013;310:1947-63.
29. Porter ME, Lee TH. The Strategy That Will Fix Health Care. *Harvard Business Review* 2013.
30. Grossmann C, Goolsby WA, Olsen L, McGinnis JM. Engineering a Learning Healthcare System: A Look at the Future: Workshop Summary. Washington D.C.: The National Academies Press; 2011.
31. Vicini J, Stempel J. WRAPUP 4-US top court upholds healthcare law in Obama triumph. *Reuters* 2012.
32. Foundation TKF. Summary of the Affordable Care Act. Focus on Health Reform: The Henry J. Kaiser Family Foundation; 2013.
33. Harrison S, Kennedy S, Pollard L. How Hospitals Are Shifting Resources Post-Reform. *Becker's Hospital CFO: Becker's Hospital Review*; 2014.
34. Rosenbaum S. The Patient Protection and Affordable Care Act: implications for public health policy and practice. *Public Health Rep* 2011;126:130-5.
35. ACHE. Top Issues Confronting Hospitals: 2013. Research & Resource: American College of Health Executives; 2013.
36. Davis SB, Robinson, Phillip J. Healthcare Providers under Pressure: Make the Most of Challenging Times Accounting Matters. *Association of Healthcare Internal Auditors* 2010.
37. Meyer H, Evans M. Outlook 2014: The year ahead in healthcare business. *Modern Healthcare* 2014.
38. Mertz G. What Healthcare Reform Means for Physicians *Physician's Practice Your Practice Your way* 2013.
39. Clough J, Adams M, Afable R, et al. Hospitals and Care Systems of Future. *American Hospital Association* 2011.
40. Grol R. Personal paper. Beliefs and evidence in changing clinical practice. *BMJ* 1997;315:418-21.
41. Institute of Medicine (US) Roundtable on Value & Science-Driven Health Care. U.S. Healthcare Data Today: Current State of Play. Washington, DC: Institute of Medicine 2010.

42. Kalakota R. Informatics or Analytics? Understanding Digital Health Use Cases. *Business Analytics* 302013.
43. Committee on Quality of Health Care in America - Institute of Medicine. Crossing the Quality Chasm: A New Health System for the 21st Century. *Journal of the American Medical Association: National Academies Press*; 2001.
44. Institute of Medicine (IOM). Beyond the HIPAA Privacy Rule: Enhancing Privacy, Improving Health Through Research. Washington, DC: Institute of Medicine (IOM), Committee on Health Research and the Privacy of Health Information: The HIPAA Privacy Rule; 2009.
45. Safran C, Bloomrosen M, Hammond WE, et al. Toward a national framework for the secondary use of health data: an American Medical Informatics Association White Paper. *J Am Med Inform Assoc* 2007;14:1-9.
46. Wickramasinghe N, Schaffer JL. Creating knowledge-driven healthcare processes with the Intelligence Continuum. *Int J Electron Healthc* 2006;2:164-74.
47. Smith SE, Drake LE, Harris JG, Watson K, Pohlner PG. Clinical informatics: a workforce priority for 21st century healthcare. *Aust Health Rev* 2011;35:130-5.
48. French CS. *Data Processing and Information Technology*. 10 ed: Cengage Learning Business Press; 1996.
49. Shah ND, Pathak J. Why Health Care May Finally Be Ready for Big Data. *Harvard Business Review* 2014.
50. *Quality Profiles: Focus on Supporting Quality Improvement Through the Use of Health Information Technology*: Pfizer and NCQA; 2009.
51. Goodwin S. Data rich, information poor (DRIP) syndrome: is there a treatment? *Radiol Manage* 1996;18:45-9.
52. Blumenthal D. Launching HITECH. *N Engl J Med* 2010;362:382-5.
53. Blumenthal D, Tavenner M. The "meaningful use" regulation for electronic health records. *N Engl J Med* 2010;363:501-4.
54. *Health Information Technology in the United States: Progress and Challenges Ahead*, 2014. Robert Wood Johnson Foundation; 2014.
55. Jaén CR. Successful health information technology implementation requires practice and health care system transformation. *Ann Fam Med* 2011;9:388-9.

56. AHRQ. Health Information Technology: Best Practices Transforming Quality and Efficiency Barriers to HIT Implementation: Agency for Healthcare Research and Quality; 2012.
57. Cresswell K, Sheikh A. Organizational issues in the implementation and adoption of health information technology innovations: an interpretative review. *Int J Med Inform* 2013;82:e73-86.
58. Friedman J, Metzler I, Detmer D, Selzer D, Meara JG. Health information technology, meaningful use criteria, and their effects on surgeons. *Bull Am Coll Surg* 2012;97:12-9.
59. Sanders D, Burton DA, Protti D. The Healthcare Analytics Adoption Model: A Framework and Roadmap. *Health Catalyst*; 2013.
60. Biesdorf S, Niedermann F. Healthcare's Digital Future. Insights from our international survey can help healthcare organizations plan their next moves in the journey toward full digitization: McKinsey & Company; 2014.
61. Garrett P, Seidman J. EMR vs EHR - What is the Difference? *Electronic Health and Medical Record: Health IT Buzz*; 2011.
62. Clayton PD. Obstacles to the Implementation and Acceptance of Electronic Medical Record Systems. Washington, DC: The National Academies Press; 2005.
63. O'Malley AS, Grossman JM, Cohen GR, Kemper NM, Pham HH. Are electronic medical records helpful for care coordination? Experiences of physician practices. *J Gen Intern Med* 2010;25:177-85.
64. Health Information and Management System Society (HIMSS). *Electronic Health Record*
65. Menachemi N, Collum TH. Benefits and drawbacks of electronic health record systems. *Risk Manag Healthc Policy* 2011;4:47-55.
66. Burton D. How to Unlock the Analytic Value of Your EHR. *Health Catalyst Insights* 2014.
67. Cortada JW, Gordon D, Lenihan B. The value of analytics in healthcare: From insights to outcomes IBM Institute for Business Value; 2012.
68. Philips. Making Sense of The Chaos: From Data Mining to Data Meaning. Koninklijke Philips Electronics N.V.: Philips Design; 2012.
69. Moore-Colyer R. Big data success needs analytics and programming skills. *V3*; 2014.

70. SAS. Big Data: What it is and why it matters.
71. Grossmann C, Goodby AW, Olsen LA, McGinnis JM. Clinical Data as the Basic Staple of Health Learning: Creating and Protecting a Public Good: Workshop Summary Washington, DC: The National Academies Press; 2010.
72. Strome T. Root Causes: Mitigating the Gap and in Healthcare Analytics. TechTarget; 2014.
73. Ferguson D. Healthcare Analytics-Where to Begin. National Research Corporation; 2013.
74. Sackett DL. Evidence-based medicine. *Semin Perinatol* 1997;21:3-5.
75. Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. Evidence based medicine: what it is and what it isn't. *BMJ* 1996;312:71-2.
76. Bennett S, Tooth L, McKenna K, et al. Perceptions of Evidence-Based Practice: A Survey Of Australian Occupational Therapists. *Australian Occupational Therapy Journal* 2003;13-22.
77. Majid S, Foo S, Luyt B, et al. Adopting evidence-based practice in clinical decision making: nurses' perceptions, knowledge, and barriers. *J Med Libr Assoc* 2011;99:229-36.
78. Youngblut JM, Brooten D. Evidence-based nursing practice: why is it important? *AACN Clin Issues* 2001;12:468-76.
79. Alper BS, Hand JA, Elliott SG, et al. How much effort is needed to keep up with the literature relevant for primary care? *J Med Libr Assoc* 2004;92:429-37.
80. van Dijk N, Hooft L, Wieringa-de Waard M. What are the barriers to residents' practicing evidence-based medicine? A systematic review. *Acad Med* 2010;85:1163-70.
81. Swennen MH, van der Heijden GJ, Boeije HR, et al. Doctors' perceptions and use of evidence-based medicine: a systematic review and thematic synthesis of qualitative studies. *Acad Med* 2013;88:1384-96.
82. Sadeghi-Bazargani H, Sadegh Tabrizi J, Azami-Aghdash S. Barriers to evidence-based medicine: a systematic review. *Journal of Evaluation in Clinical Practice: John Wiley & Sons, Ltd.*; 2014:793-802.
83. McQueen MJ. Overview of evidence-based medicine: challenges for evidence-based laboratory medicine. *Clin Chem* 2001;47:1536-46.

84. Sackett DL, Richardson WS, W. R, R.B. H. Evidence-based medicine: how to practice and teach EBM. Edinburgh, Scotland. . Churchill Livingstone 2000.
85. IOM. Evidence-Based Medicine and the Changing Nature of Healthcare: 2007 IOM Annual Meeting Summary. In: Medicine Io, ed. Washington, DC: National Academies Press; 2008.
86. IOM. Evidence-Based Medicine and the Changing Nature of Healthcare: 2007 IOM Annual Meeting Summary. In: Cortese DA, ed. The Need for Better Evidence. Washington, DC: National Academies Press; 2008.
87. Juurlink DN, Mamdani MM, Lee DS, et al. Rates of hyperkalemia after publication of the Randomized Aldactone Evaluation Study. *N Engl J Med* 2004;351:543-51.
88. Croft P, Malmivaara A, van Tulder M. The pros and cons of evidence-based medicine. *Spine (Phila Pa 1976)* 2011;36:E1121-5.
89. Bouffard M, Reid G. The good, the bad, and the ugly of evidence-based practice. *Adapt Phys Activ Q* 2012;29:1-24.
90. Del Mar C, Glasziou P, Mayer D. Teaching evidence based medicine. *BMJ* 2004;329:989-90.
91. Haynes RB. Where's the meat in clinical journals? : ACP Journal Club; 1993;993;119:A22.
92. Druss BG, Marcus SC. Growth and decentralization of the medical literature: implications for evidence-based medicine. *J Med Libr Assoc* 2005;93:499-501.
93. Rezazadeh E, Hachesu PR, Rezapoor A, Alireza K. Evidence-based medicine: going beyond improving care provider viewpoints, using and challenges upcoming. *J Evid Based Med* 2014;7:26-31.
94. Sadeghi M, Khanjani N, Motamedi F, Saber M, Rad GS. Familiarity of medical residents at Kerman Medical University with evidence based medicine databases. *J Res Med Sci* 2011;16:1372-7.
95. Park M. Development of Evidence based Nursing Practice Guideline Document Model for Electronic Distribution. *J Korean Soc Med Inform.* ; 2004.
96. Young JM, Solomon MJ. How to critically appraise an article. *Nat Clin Pract Gastroenterol Hepatol* 2009;6:82-91.

97. Nicholson LJ, Warde CM, Boker JR. Faculty training in evidence-based medicine: improving evidence acquisition and critical appraisal. *J Contin Educ Health Prof* 2007;27:28-33.
98. Green ML. Evidence-based medicine training in internal medicine residency programs a national survey. *J Gen Intern Med* 2000;15:129-33.
99. Grimshaw JM, Eccles MP, Walker AE, Thomas RE. Changing physicians' behavior: what works and thoughts on getting more things to work. *J Contin Educ Health Prof* 2002;22:237-43.
100. Hammer GP, du Prel JB, Blettner M. Avoiding bias in observational studies: part 8 in a series of articles on evaluation of scientific publications. *Dtsch Arztebl Int* 2009;106:664-8.
101. Jepsen P, Johnsen SP, Gillman MW, Sørensen HT. Interpretation of observational studies. *Heart* 2004;90:956-60.
102. Solomons NM, Spross JA. Evidence-based practice barriers and facilitators from a continuous quality improvement perspective: an integrative review. *J Nurs Manag* 2011;19:109-20.
103. Shortell SM, Bennett CL, Byck GR. Assessing the impact of continuous quality improvement on clinical practice: what it will take to accelerate progress. *Milbank Q* 1998;76:593-624, 510.
104. Hall D, Zezza M. Developing an Incentives Playbook: Aligning Influences in the Era of Reform. *American Journal of Managed Care* 201.
105. Evans M. Consolidation Creating Giant Hospital Systems. *Modern Healthcare* 2014.
106. Kocher R, Sahnil NR. Hospitals' Race to Employ Physicians — The Logic behind a Money-Losing Proposition. *The New England Journal of Medicine* 2011:1790-3.
107. Miltenberger RG. *Behavior Modification: Principles and Procedures*. 5 ed: Wadsworth Publishing; 2011.
108. Torchiana DF, Colton DG, Rao SK, Lenz SK, Meyer GS, Ferris TG. Massachusetts General Physicians Organization's quality incentive program produces encouraging results. *Health Aff (Millwood)* 2013;32:1748-56.
109. Mehrotra A, Sorbero ME, Damberg CL. Using the lessons of behavioral economics to design more effective pay-for-performance programs. *Am J Manag Care* 2010;16:497-503.

110. Gneezy U, Rustichini A. Pay Enough or Don't Pay at All. *The Quarterly Journal of Economics* 2000;115:791-810.
111. McDonald R, Harrison S, Checkland K, Campbell SM, Roland M. Impact of financial incentives on clinical autonomy and internal motivation in primary care: ethnographic study. *British Medical Journal* 2007;334.
112. Cunningham AT, Lynch TJ, Cassel CK. Catalyzing Physician Engagement: The Roles of Intrinsic and Extrinsic Motivation. *ABIM Foundation Forum* 2013.
113. Kolstad J. Information and quality when motivation is intrinsic: Evidence from surgeon report cards. . *American Economic Review*;103:2875-910.
114. Meeker D, Knight TK, Friedberg MW, et al. Nudging guideline-concordant antibiotic prescribing: a randomized clinical trial. *JAMA Intern Med* 2014;174:425-31.
115. Curry LA, Spatz E, Cherlin E, et al. What distinguishes top-performing hospitals in acute myocardial infarction mortality rates? A qualitative study. *Ann Intern Med* 2011;154:384-90.
116. Flodgren G, Eccles MP, Shepperd S, Scott A, Parmelli E, Beyer FR. An overview of reviews evaluating the effectiveness of financial incentives in changing healthcare professional behaviours and patient outcomes. *Cochrane Database Syst Rev* 2011:CD009255.
117. Grossman C, Powers B, McGinnis JM. *Learning What Works*. Washington, DC: National Academy of Sciences; 2011. Report No.: ISBN-13: 978-0-309-12068-5.
118. Olsen L, Aisner D, McGinnis JM. *The Learning Healthcare System*. Washington, DC: Institute of Medicine; 2007.
119. Corrigan J, McNeill D. Building organizational capacity: a cornerstone of health system reform. *Health Aff (Millwood)* 2009;28:w205-15.
120. Ortiz E, Clancy CM, AHRQ. Use of information technology to improve the quality of health care in the United States. *Health Serv Res* 2003;38:xi-xxii.
121. Snyder CF, Wu AW, Miller RS, Jensen RE, Bantug ET, Wolff AC. The role of informatics in promoting patient-centered care. *Cancer J* 2011;17:211-8.
122. Rohm BWT, Rohm CET. Clinical Informatics: A New Paradigm for Advances in BioMedical Informatics. *Clinical Informatics* 2007;3:100-8.

123. Health Informatics Society of Australia. A Review of the Australian Health Informatics Workforce: A Report by the Health Informatics Society of Australia. Health Informatics Society of Australia Melbourne 2009.
124. Hersh W. New IOM Report on Implementing the Learning Healthcare System: It's All in the Information. Informatics Professor 2012.
125. Davis DA, Thomson MA, Oxman AD, Haynes RB. Changing physician performance. A systematic review of the effect of continuing medical education strategies. JAMA 1995;274:700-5.
126. Murphy GJ, Reeves BC, Rogers CA, Rizvi SI, Culliford L, Angelini GD. Increased mortality, postoperative morbidity, and cost after red blood cell transfusion in patients having cardiac surgery. Circulation 2007;116:2544-52.
127. Anonymous. Actionable Patient Safety Solution (APSS) #3:SUB-OPTIMAL RED Blood Cell Transfusion Patient Safety.Org; 2014.
128. Agency for Healthcare Research and Quality. Inpatient Sample. Agency for Healthcare Research and Quality; 1997-2007.
129. Patient Safety Movement. Actionable Patient Safety Solution (APSS) #3:SUB-Optimal Red Blood Cell Transfusion Patient Safety.Org; 2014.
130. AHRQ. Inpatient Sample. Agency for Healthcare Research and Quality; 1997-2007.
131. Puca KE, Fredrick N, Slapak C. Beyond the Lab into Patient Blood Management American Society for Clinical Pathology; 2014.
132. Analysis PHA. Standardization of blood utilization practices could provide opportunity for improved outcomes, reduced costs Premier; 2012.
133. Toner RW, Pizzi L, Leas B, Ballas SK, Quigley A, Goldfarb NI. Costs to hospitals of acquiring and processing blood in the US: a survey of hospital-based blood banks and transfusion services. Appl Health Econ Health Policy 2011;9:29-37.
134. The cost of blood: multidisciplinary consensus conference for a standard methodology. Transfus Med Rev 2005;19:66-78.
135. Shander A, Hofmann A, Gombotz H, Theusinger OM, Spahn DR. Estimating the cost of blood: past, present, and future directions. Best Pract Res Clin Anaesthesiol 2007;21:271-89.
136. Corporation M. New Published Study Finds the Cost of Blood Transfusions is Significantly Underestimated, Establishes True Cost at \$522 to \$1,183 Per Unit. 2014.

137. Crémieux PY, Barrett B, Anderson K, Slavin MB. Cost of outpatient blood transfusion in cancer patients. *J Clin Oncol* 2000;18:2755-61.
138. Patterson JA, Roberts CL, Isbister JP, et al. What factors contribute to hospital variation in obstetric transfusion rates? *Vox Sang* 2015;108:37-45.
139. Carson JL, Hill S, Carless P, Hébert P, Henry D. Transfusion triggers: a systematic review of the literature. *Transfus Med Rev* 2002;16:187-99.
140. Carson JL, Armas-Loughran B. Blood transfusion: less is more? *Crit Care Med* 2003;31:2409-10.
141. Corwin HL, Shorr AF. Red blood cell transfusion in the critically ill: when is it time to say enough? *Crit Care Med* 2009;37:2114-6.
142. Shander A, Fink A, Javidroozi M, et al. Appropriateness of allogeneic red blood cell transfusion: the international consensus conference on transfusion outcomes. *Transfus Med Rev* 2011;25:232-46.e53.
143. TxMD. Success in Cardiac Surgery Blood Management: 45% Reduction in Coronary Artery Bypass Graft (CABG) Intraoperative Transfusion BloodCenter of Wisconsin.
144. McQuilten ZK, Andrianopoulos N, Wood EM, et al. Transfusion practice varies widely in cardiac surgery: Results from a national registry. *J Thorac Cardiovasc Surg* 2014;147:1684-90.
145. Hébert PC, Wells G, Martin C, et al. Variation in red cell transfusion practice in the intensive care unit: a multicentre cohort study. *Crit Care* 1999;3:57-63.
146. Bennett-Guerrero E, Zhao Y, O'Brien SM, et al. Variation in use of blood transfusion in coronary artery bypass graft surgery. *JAMA* 2010;304:1568-75.
147. Lozano M, Cid J. Transfusion medicine as of 2014. *F1000Prime Rep* 2014;6:105.
148. Hébert PC. Transfusion requirements in critical care (TRICC): a multicentre, randomized, controlled clinical study. Transfusion Requirements in Critical Care Investigators and the Canadian Critical care Trials Group. *Br J Anaesth* 1998;81 Suppl 1:25-33.
149. Carless PA, Henry DA, Carson JL, Hebert PP, McClelland B, Ker K. Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. *Cochrane Database Syst Rev* 2010:CD002042.

150. Blumberg N, Hicks GL, Heal JM, Rogers M. Study Links Blood Transfusions to Surgery Complications in Women. University of Rochester Medical Center 2007.
151. Rohde JM, Dimcheff DE, Blumberg N, et al. Health care-associated infection after red blood cell transfusion: a systematic review and meta-analysis. *JAMA* 2014;311:1317-26.
152. Isbister JP, Shander A, Spahn DR, Erhard J, Farmer SL, Hofmann A. Adverse blood transfusion outcomes: establishing causation. *Transfus Med Rev* 2011;25:89-101.
153. Weisel RD, Dennis RC, Manny J, Mannick JA, Valeri CR, Hechtman HB. Adverse effects of transfusion therapy during abdominal aortic aneurysectomy. *Surgery* 1978;83:682-90.
154. Spahn DR. Anemia and patient blood management in hip and knee surgery: a systematic review of the literature. *Anesthesiology* 2010;113:482-95.
155. Carson JL, Terrin ML, Noveck H, et al. Liberal or restrictive transfusion in high-risk patients after hip surgery. *N Engl J Med* 2011;365:2453-62.
156. Society for The Advancement of Blood Management. Transfusion Overuse – Exposing and International Problem and Patient Safety Issue. .
157. Petrides M, Aubuchon JP. To transfuse or not to transfuse: An assessment of risks and benefits. In: Mintz PD, ed. *Transfusion therapy: Clinical principles and practice*. 3rd ed. Bethesda, MD: AABB Press, 2011. AABB Press. Bethesda, MD: *Transfusion therapy: Clinical principles and practice*; 2011.
158. Goodnough LT, Shander A. Risk and complications of blood transfusions: optimizing outcomes for patients with chemotherapy induced anemia. *Advanced Studies in Medicine* 2008:357–62.
159. Whitaker BI, Hinkins S. The 2011 National Blood Collection and Utilization Survey Report. the U.S. Department of Health and Human Services 2011.
160. Whitaker BI, Green J, King MR, et al. The 2007 National Blood Collection and Utilization Survey Report: The United States Department of Health and Human Services; 2007.
161. Busch MP, Glynn SA, Stramer SL, et al. A new strategy for estimating risks of transfusion-transmitted viral infections based on rates of detection of recently infected donors. *Transfusion* 2005;45:254-64.
162. Carson JL, Grossman BJ, Kleinman S, et al. Red blood cell transfusion: a clinical practice guideline from the AABB. *Ann Intern Med* 2012;157:49-58.

163. Cullen KA, Arguin PM, Division of Parasitic Diseases and Malaria CfGH, Centers for Disease Control and Prevention (CDC). Malaria surveillance--United States, 2011. *MMWR Surveill Summ* 2013;62:1-17.
164. Goodnough LT, Shander A, Brecher ME. Transfusion medicine: looking to the future. *Lancet* 2003;361:161-9.
165. Kevin L. Risky Business? The Relative Infectious Risks of Blood Transfusion. The Bloody Truth Medical Blog; The Truth About Blood Transfusions Patient Safety 2012.
166. Li G, Rachmale S, Kojicic M, et al. Incidence and transfusion risk factors for transfusion-associated circulatory overload among medical intensive care unit patients. *Transfusion* 2011;51:338-43.
167. ABC. Infectious Risks of Blood Transfusion. . Washington, DC. : Blood Bulletin. America's Blood Centers. ; 2001.
168. ABC. Non-infectious Serious Hazards of Transfusion. Blood Bulletin Washington, DC:: America's Blood Centers.; 2002.
169. CDC. Fatal West Nile virus infection after probable transfusion-associated transmission--Colorado, 2012. *MMWR Morb Mortal Wkly Rep* 2013;62:622-4.
170. Prowse C, Ludlam CA, Yap PL. Human parvovirus B19 and blood products. *Vox Sang* 1997;72:1-10.
171. Schreiber GB, Busch MP, Kleinman SH, Korelitz JJ. The risk of transfusion-transmitted viral infections. The Retrovirus Epidemiology Donor Study. *N Engl J Med* 1996;334:1685-90.
172. Stramer SL, Glynn SA, Kleinman SH, et al. Detection of HIV-1 and HCV infections among antibody-negative blood donors by nucleic acid-amplification testing. *N Engl J Med* 2004;351:760-8.
173. Stramer SL. Current risks of transfusion-transmitted agents: a review. *Arch Pathol Lab Med* 2007;131:702-7.
174. AABB. Technical Manual, 17th edition. Bethesda, MD: AABB Press; 2011.
175. AABB. Update to Transfusion. AABB Resources. 2009:107-9S.
176. Crosse MG. Blood Supply: Transfusion-associated risks: Diane Pub Co; 1997.

177. Young C, Chawla A, Berardi V, et al. Preventing transfusion-transmitted babesiosis: preliminary experience of the first laboratory-based blood donor screening program. *Transfusion* 2012;52:1523-9.
178. Services UB. Risks Associated with Transfusion. United Blood Services for Hospitals and Physicians.
179. AABB. Non-Infectious Hazards of Transfusion. Bethesda, MD2008.
180. Linden JV, Wagner K, Voytovich AE, Sheehan J. Transfusion errors in New York State: an analysis of 10 years' experience. *Transfusion* 2000;40:1207-13.
181. Marik PE, Corwin HL. Efficacy of red blood cell transfusion in the critically ill: a systematic review of the literature. *Crit Care Med* 2008;36:2667-74.
182. Hajjar LA, Vincent JL, Galas FR, et al. Transfusion requirements after cardiac surgery: the TRACS randomized controlled trial. *JAMA* 2010;304:1559-67.
183. Hill SR, Carless PA, Henry DA, et al. Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. *Cochrane Database Syst Rev* 2002;CD002042.
184. Klein HG, Spahn DR, Carson JL. Red blood cell transfusion in clinical practice. *Lancet* 2007;370:415-26.
185. Shander A, Gross I, Hill S, et al. A new perspective on best transfusion practices. *Blood Transfus* 2013;11:193-202.
186. Long TR, Curry TB, Stemmann JL, et al. Changes in red blood cell transfusion practice during the turn of the millennium: a retrospective analysis of adult patients undergoing elective open abdominal aortic aneurysm repair using the Mayo database. *Ann Vasc Surg* 2010;24:447-54.
187. Vuille-Lessard E, Boudreault D, Girard F, Ruel M, Chagnon M, Hardy JF. Red blood cell transfusion practice in elective orthopedic surgery: a multicenter cohort study. *Transfusion* 2010;50:2117-24.
188. Wass CT, Long TR, Faust RJ, Yaszemski MJ, Joyner MJ. Changes in red blood cell transfusion practice during the past two decades: a retrospective analysis, with the Mayo database, of adult patients undergoing major spine surgery. *Transfusion* 2007;47:1022-7.
189. Ferraris VA, Brown JR, Despotis GJ, et al. 2011 Update to The Society of Thoracic Surgeons and the Society of Cardiovascular Anesthesiologists Blood Conservation Clinical Practice Guidelines. *Ann Thorac Surg* 2011.

190. Maddux FW, Dickinson TA, Rilla D, et al. Institutional variability of intraoperative red blood cell utilization in coronary artery bypass graft surgery. *Am J Med Qual* 2009;24:403-11.
191. Turgeon AF, Fergusson DA, Doucette S, et al. Red blood cell transfusion practices amongst Canadian anesthesiologists: a survey. *Can J Anaesth* 2006;53:344-52.
192. Spahn DR, Theusinger OM, Hofmann A. Patient blood management is a win-win: a wake-up call. *Br J Anaesth* 2012;108:889-92.
193. Goodnough LT, Shander A, Spivak JL, et al. Detection, evaluation, and management of anemia in the elective surgical patient. *Anesth Analg* 2005;101:1858-61.
194. Graham-Stewart CW. A clinical survey of blood-transfusion. *Lancet* 1960;2:421-4.
195. Reece RL, Beckett RS. Epidemiology of single-unit transfusion. A one-year experience in a community hospital. *JAMA* 1966;195:801-16.
196. Murphy MF, Wallington TB, Kelsey P, et al. Guidelines for the clinical use of red cell transfusions. *Br J Haematol* 2001;113:24-31.
197. Napolitano LM, Kurek S, Luchette FA, et al. Clinical practice guideline: red blood cell transfusion in adult trauma and critical care. *Crit Care Med* 2009;37:3124-57.
198. Gaydos LA, Freireich EJ, Mantel N. The quantitative relation between platelet count and hemorrhage in patients with acute leukemia. *N Engl J Med* 1962;266:905-9.
199. Slichter SJ. Relationship between platelet count and bleeding risk in thrombocytopenic patients. *Transfus Med Rev* 2004;18:153-67.
200. Schiffer CA, Anderson KC, Bennett CL, et al. Platelet transfusion for patients with cancer: clinical practice guidelines of the American Society of Clinical Oncology. *J Clin Oncol* 2001;19:1519-38.
201. Heddle NM, Cook RJ, Sigouin C, et al. A descriptive analysis of international transfusion practice and bleeding outcomes in patients with acute leukemia. *Transfusion* 2006;46:903-11.
202. Wall MH, Prielipp RC. Transfusion in the operating room and the intensive care unit: current practice and future directions. *Int Anesthesiol Clin* 2000;38:149-69.
203. Roback JD, Caldwell S, Carson J, et al. Evidence-based practice guidelines for plasma transfusion. *Transfusion* 2010;50:1227-39.

204. SABM. Patient Blood Management. SABM's Annual Meeting. sabm.org: Society for The Advancement of Blood Management.
205. Hébert PC, Wells G, Blajchman MA, et al. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. Transfusion Requirements in Critical Care Investigators, Canadian Critical Care Trials Group. *N Engl J Med* 1999;340:409-17.
206. Carson JL, Duff A, Berlin JA, et al. Perioperative blood transfusion and postoperative mortality. *JAMA* 1998;279:199-205.
207. Krausz MM, Dennis RC, Utsunomiya T, et al. Cardiopulmonary function following transfusion of three red blood cell products in elective abdominal aortic aneurysmectomy. *Ann Surg* 1981;194:616-24.
208. Johnson RG, Thurer RL, Kruskall MS, et al. Comparison of two transfusion strategies after elective operations for myocardial revascularization. *J Thorac Cardiovasc Surg* 1992;104:307-14.
209. Carson JL, Carless PA, Hébert PC. Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. *Cochrane Database Syst Rev* 2012;4:CD002042.
210. JC. Joint Commission Perspectives. The Joint Commission Continues to Study Overuse Issues.: The Joint Commission; 2012:4-8.
211. McCarthy LJ, Emmett D, Smith S, Holland V. Evidence-based medicine in transfusion medicine: an update. *ISBT Science Series*; 2007:36-40.
212. Blajchman MA. Landmark studies that have changed the practice of transfusion medicine. *Transfusion* 2005;45:1523-30.
213. Wu WC, Rathore SS, Wang Y, Radford MJ, Krumholz HM. Blood transfusion in elderly patients with acute myocardial infarction. *N Engl J Med* 2001;345:1230-6.
214. Wu WC, Trivedi A, Friedmann PD, et al. Association between hospital intraoperative blood transfusion practices for surgical blood loss and hospital surgical mortality rates. *Ann Surg* 2012;255:708-14.
215. Llewelyn CA, Taylor RS, Todd AA, et al. The effect of universal leukoreduction on postoperative infections and length of hospital stay in elective orthopedic and cardiac surgery. *Transfusion* 2004;44:489-500.
216. Go JT, Vaughan-Sarrazin M, Auerbach A, et al. Do hospitalists affect clinical outcomes and efficiency for patients with acute upper gastrointestinal hemorrhage (UGIH)? *J Hosp Med* 2010;5:133-9.

217. Friedman MT. Blood transfusion practices: a little consistency please. *Blood Transfus* 2011;9:362-5.
218. Corwin HL, Gettinger A, Pearl RG, et al. The CRIT Study: Anemia and Blood Transfusion in the Critically Ill - Current Clinical Practice in the United States. *Crit Care Med*. 32(1); 2004.
219. Rana R, Afessa B, Keegan MT, et al. Evidence-based red cell transfusion in the critically ill: quality improvement using computerized physician order entry. *Crit Care Med* 2006;34:1892-7.
220. Vincent JL, Baron JF, Reinhart K, et al. Anemia and blood transfusion in critically ill patients. *JAMA* 2002;288:1499-507.
221. Roubinian NH, Murphy EL, Swain BE, et al. Predicting red blood cell transfusion in hospitalized patients: role of hemoglobin level, comorbidities, and illness severity. *BMC Health Serv Res* 2014;14:213.
222. Villanueva C, Colomo A, Bosch A, et al. Transfusion strategies for acute upper gastrointestinal bleeding. *N Engl J Med* 2013;368:11-21.
223. Longstreth GF. Epidemiology of hospitalization for acute upper gastrointestinal hemorrhage: a population-based study. *Am J Gastroenterol* 1995;90:206-10.
224. So-Osman C, Cicilia J, Brand A, Schipperus M, Berning B, Scherjon S. Triggers and appropriateness of red blood cell transfusions in the postpartum patient--a retrospective audit. *Vox Sang* 2010;98:65-9.
225. Silverman JA, Barrett J, Callum JL. The appropriateness of red blood cell transfusions in the peripartum patient. *Obstet Gynecol* 2004;104:1000-4.
226. Qian F, Osler TM, Eaton MP, et al. Variation of blood transfusion in patients undergoing major noncardiac surgery. *Ann Surg* 2013;257:266-78.
227. Welsby I, Crow J, Bandarenko N, Lappas G, Phillips-Bute B, Stafford-Smith M. A clinical prediction tool to estimate the number of units of red blood cells needed in primary elective coronary artery bypass surgery. *Transfusion* 2010;50:2337-43.
228. Sherwood MW, Wang Y, Curtis JP, Peterson ED, Rao SV. Patterns and outcomes of red blood cell transfusion in patients undergoing percutaneous coronary intervention. *JAMA* 2014;311:836-43.

229. Carson JL, Terrin ML, Barton FB, et al. A pilot randomized trial comparing symptomatic vs. hemoglobin-level-driven red blood cell transfusions following hip fracture. *Transfusion* 1998;38:522-9.
230. Banerjee S, Issa K, Kapadia BH, et al. Intraoperative nonpharmacotherapeutic blood management strategies in total knee arthroplasty. *J Knee Surg* 2013;26:387-93.
231. Newman ET, Watters TS, Lewis JS, et al. Impact of perioperative allogeneic and autologous blood transfusion on acute wound infection following total knee and total hip arthroplasty. *J Bone Joint Surg Am* 2014;96:279-84.
232. Friedman R, Homering M, Holberg G, Berkowitz SD. Allogeneic blood transfusions and postoperative infections after total hip or knee arthroplasty. *J Bone Joint Surg Am* 2014;96:272-8.
233. Schwarzkopf R, Chung C, Park JJ, Walsh M, Spivak JM, Steiger D. Effects of perioperative blood product use on surgical site infection following thoracic and lumbar spinal surgery. *Spine (Phila Pa 1976)* 2010;35:340-6.
234. Woods BI, Rosario BL, Chen A, et al. The association between perioperative allogeneic transfusion volume and postoperative infection in patients following lumbar spine surgery. *J Bone Joint Surg Am* 2013;95:2105-10.
235. Levi N, Sandberg T. Blood transfusion and postoperative wound infection in intracapsular femoral neck fractures. *Bull Hosp Jt Dis* 1998;57:69-73.
236. Verlicchi F, Desalvo F, Zanotti G, Morotti L, Tomasini I. Red cell transfusion in orthopaedic surgery: a benchmark study performed combining data from different data sources. *Blood Transfus* 2011;9:383-7.
237. Shander A, Javidroozi M, Ozawa S, Hare GM. What is really dangerous: anaemia or transfusion? *Br J Anaesth* 2011;107 Suppl 1:i41-59.
238. Haynes SL, Torella F. The role of hospital transfusion committees in blood product conservation. *Transfus Med Rev* 2004;18:93-104.
239. Liumbruno GM, Rafanelli D. Appropriateness of blood transfusion and physicians' education: a continuous challenge for Hospital Transfusion Committees? *Blood Transfus* 2012;10:1-3.
240. Haspel RL, Lin Y, Mallick R, et al. Internal medicine resident knowledge of transfusion medicine: results from the BEST-TEST international education needs assessment. *Transfusion* 2014.

241. Clark P, Rennie I, Rawlinson S. Quality improvement report: Effect of a formal education programme on safety of transfusions. *BMJ* 2001;323:1118-20.
242. Louw VJ, Nel MM, Hay JF. Postgraduate education in transfusion medicine in the absence of formal residency training: assessment of factors needed to develop and sustain a postgraduate diploma program. *Transfus Apher Sci* 2013;49:681-6.
243. Corwin HL, Theus JW, Cargile CS, Lang NP. Red blood cell transfusion: impact of an education program and a clinical guideline on transfusion practice. *J Hosp Med* 2014;9:745-9.
244. Ferraris VA, Ferraris SP, Saha SP, et al. Perioperative blood transfusion and blood conservation in cardiac surgery: the Society of Thoracic Surgeons and The Society of Cardiovascular Anesthesiologists clinical practice guideline. *Ann Thorac Surg* 2007;83:S27-86.
245. Goodnough LT, Shander A. Patient blood management. *Anesthesiology* 2012;116:1367-76.
246. Shander A, Javidroozi M. Patient Blood Management: Beyond Sensible Use of Blood for Better Outcomes Central Jersey Blood Center 2014.
247. Shander A. Committee News: Committee on Blood Management. *AMERICAN Society of Anesthesiologists* 2013.
248. Goodnough LT, Shander A. Blood management. *Arch Pathol Lab Med* 2007;131:695-701.
249. Shander A, Moskowitz DM, Javidroozi M. Blood conservation in practice: an overview. *Br J Hosp Med (Lond)* 2009;70:16-21.
250. Shander A, Waters J. Developments in patient blood management. *American Society of Anesthesiologists Newsletter* 75:30 –22011.
251. Shander A. Patient Blood Management: a multidisciplinary strategy to reduce the need for allogeneic blood. *European Society of Anaesthesiology* 2011.
252. Advisory Q. Appropriate Use of Medical Resources: Patient Blood Management. *American Hospital Association Quality Advisory* 2014.
253. Dzik WH. The Changing Landscape of Transfusion Medicine: 2004–2015. *Transfusion Medicine*; 2005:69-82.
254. Thomson A, Farmer S, Hofmann A, Isbister J, Shander A. Patient blood management – a new paradigm for transfusion medicine? . *ISBT Science Series* 2009:423-35.

255. Thurer R. GNYHA Symposium Patient Blood Management. HaemoneticsThe Blood Management Company 2014.
256. Government WA. Hospital Patient Blood Management Communication Strategies. Government of Western Australia2012.
257. Tan JKH. Health Management Information Systems: Methods and Practical Applications: Aspen Publishers Inc.; 2001.
258. IMPACT. Actionable Data for Measureable Results. Haemonetics.
259. Jadwin D. Improving Blood Transfusion; Hemoglobin Level an Inadequate Metric. Lab Soft News2014.
260. Management SftAoB. Transfusion Overuse Exposing an International Problem and Patient Safety Issue - For Nurses2014.
261. Hewitt D, Richards T. Challenges in evidence-based medicine. Can Fam Physician 2006;52:23-4.
262. Nelson TD, Steele RG, Mize JA. Practitioner Attitudes Toward Evidence-based Practice: Themes and Challenges. Adm Policy Ment Health & Ment Health Serv Res 2006;33:398-409.
263. M.G. T. The Evidence for Evidence-Based Practice Implementation. Rockville, MD: Agency for Healthcare Research and Quality (US); 2008.
264. Shander A, Hofmann A, Isbister J, Van Aken H. Patient blood management--the new frontier. Best Pract Res Clin Anaesthesiol 2013;27:5-10.
265. Vincent JL, Sakr Y, De Backer D, Van der Linden P. Efficacy of allogeneic red blood cell transfusions. Best Pract Res Clin Anaesthesiol 2007;21:209-19.
266. Rosenberg W, Donald A. Evidence based medicine: an approach to clinical problem-solving. BMJ 1995;310:1122-6.
267. Haines A, Jones R. Implementing findings of research. BMJ 1994;308:1488-92.
268. Chalmers I, Dickersin K, Chalmers TC. Getting to grips with Archie Cochrane's agenda. BMJ 1992;305:786-8.
269. Thyer BA. Foundation of Evidence-Based Social Work Practice. New York, New York: Oxford University Press Inc.; 2006.

270. Sudsawad P. Knowledge Translation: Introduction to Models, Strategies, and Measures. The National Center for the Dissemination of Disability Research: Center on Knowledge Translation for Disability and Rehabilitation Research; 2007.
271. Canadian Institutes of Health Research. About Knowledge Translation.2005.
272. World Health Organization. Bridging the "Know-Do" gap: Meeting on knowledge translation in global health.2005.
273. Lang ES, Wyer PC, Haynes RB. Knowledge translation: closing the evidence-to-practice gap. *Ann Emerg Med* 2007;49:355-63.
274. Canadian Institutes of Health Research. Knowledge translation strategy 2004-2009: Innovation in Action.2004.
275. Armstrong K, Kendall E. Translating knowledge into practice and policy: the role of knowledge networks in primary health care. *HIM J* 2010;39:9-17.
276. Graham ID, Logan J, Harrison MB, et al. Lost in knowledge translation: time for a map? *J Contin Educ Health Prof* 2006;26:13-24.
277. Sung NS, Crowley WF, Genel M, et al. Central challenges facing the national clinical research enterprise. *JAMA* 2003;289:1278-87.
278. Wang Y. The "Valley Of Death" In Medicine Is Not Only A Knowledge Translation But Also A Socio-Cultural And Institutional Problem. : Case Western Reserve University; 2012.
279. Browman GP. Challenges in knowledge translation: the early years of Cancer Care Ontario's Program in Evidence-Based Care. *Curr Oncol* 2012;19:27-35.
280. Grimshaw JM, Eccles MP, Lavis JN, Hill SJ, Squires JE. Knowledge translation of research findings. *Implement Sci* 2012;7:50.
281. McKenna HP, Ashton S, Keeney S. Barriers to evidence-based practice in primary care. *J Adv Nurs* 2004;45:178-89.
282. O'Connor S, Pettigrew CM. The barriers perceived to prevent the successful implementation of evidence-based practice by speech and language therapists. *Int J Lang Commun Disord* 2009;44:1018-35.
283. Haines A, Kuruville S, Borchert M. Bridging the implementation gap between knowledge and action for health: World Health Organization; 2004.

284. Harington L. Technology Today. American Association of Critical-Care Nurses 2014;25:15-7.
285. Healthcare Information and Management Systems Society (HIMSS). Dictionary of Health Information Technology Terms, Acronyms, and Organizations Chicago 2006.
286. Harington L. Technology and the Digitization of Health Care. American Association of Critical-Care Nurses 2014;25:15-7.
287. Topol E. The Creative Destruction of Medicine: How the digital Revolution Will Create a Better Healthcare. New York, New York: Basic Books; 2012.
288. Longworth DL. Accountable care organizations, the patient-centered medical home, and health care reform: what does it all mean? Cleve Clin J Med 2011;78:571-82.
289. Aiga H, Kuroiwa C, Takizawa I, Yamagata R. The reality of health information systems: challenges for standardization. Biosci Trends 2008;2:5-9.
290. Iroju O, Soriyan A, Gambo I, Olaleke J. Interoperability in Healthcare: Benefits, Challenges and Resolutions International Journal of Innovation and Applied Studies: Innovative Space of Scientific Research Journals 2013;pp. 262-70.
291. LeSueur D. 5 Reasons Healthcare Data Is Difficult to Measure. Data Quality and Governance: Health catalyst; 2014.
292. Clark J, Demster B, Solberg CJ. Managing a Data Dictionary. Journal of AHIMA; 2012;48-52.
293. Heubusch K. Interoperability: what it means, why it matters. J AHIMA 2006;77:26-30; quiz 3-4.
294. Avanavadi P. A Mediating Schema Approach to the Data Transfer between Heterogeneous Health Care Systems. Social Science Research Network 2006.
295. Capurro D, PhD MY, van Eaton E, Black R, Tarczy-Hornoch P. Availability of structured and unstructured clinical data for comparative effectiveness research and quality improvement: a multisite assessment. EGEMS (Wash DC) 2014;2:1079.
296. American Hospital Association. Clinical Integration – The Key to Real Reform. AHA.org 2010.
297. Suter E, Oelke ND, Adair CE, Armitage GD. Ten key principles for successful health systems integration. Healthc Q 2009;13 Spec No:16-23.

298. Guyatt G, Rennie D, Meade M, Cook D. Users' Guides to the Medical Literature: A Manual for Evidence-Based Clinical Practice 2008.
299. Mandl KD, Kohane IS. Escaping the EHR trap--the future of health IT. *N Engl J Med* 2012;366:2240-2.
300. Brailer DJ. Interoperability: the key to the future health care system. *Health Aff (Millwood)* 2005;Suppl Web Exclusives:W5-19-W5-21.
301. Interoperability Issues in Healthcare. http://ranger.uta.edu/~zikos/courses/5339-4392_content_repository/week4/WEEK4-Notes.pdf
302. Bensen T. Principles of Health Interoperability HL7 and SNOMED. Second ed: Springer-Verlag London; 2012.
303. HIMSS. Dictionary of Health Information Technology Terms, Acronyms, and Organizations Chicago 2006.
304. Gibbons P, Arzt N, Burke-Beebe S, et al. Coming to Terms: Scoping Interoperability for Health Care 2007.
305. Swarup D. Managing Complexity In Clinical Quality Measurement. *Health IT Outcomes* 2013.
306. Fritsch J. Three Hidden Obstacles To Healthcare Interoperability. *M*Modal: MModal IP LLC*; 2014.
307. EN13606 Association Site. Semantic interoperability of health information. CEN/ISO 13606 EHR.
308. Rosenbloom ST, Denny JC, Xu H, Lorenzi N, Stead WW, Johnson KB. Data from clinical notes: a perspective on the tension between structure and flexible documentation. *J Am Med Inform Assoc* 2011;18:181-6.
309. Ramakrishnan R. Applications of Logic Databases. New York, New York: Springer; 1995.
310. Kim K. Clinical Data Standards in Healthcare: Five Case Studies. *iHealth Report* 2005.
311. Axway. Interoperability is the Future. HIMSS 2013.
312. Healthcare Information and Management System Society. Interoperability is the Future.
313. Manos D. Interoperability Still A Barrier to Meaningful Use, Experts Find. *Healthcare IT News* 2012.

314. Berger JE. Breaking Down Another Healthcare Silo. American Journal of Managed Care 2011.
315. Smith N, O'Connell P. To Build Your Business, Smash Your Silos: Palgrave Macmillan Trade; 2012.
316. National Academy of Engineering (US) and Institute of Medicine (US) Committee on Engineering and the Health Care System. Building a Better Delivery System: A New Engineering/Health Care Partnership. Washington, DC: Institute of Medicine; 2005.
317. Reid PP, Compton WD, Grossman JH, Fanjiang G. Building a Better Delivery System: A New Engineering/Health Care Partnership National Academies Press; 2005.
318. Henry D, Buckley P, Gill G, LaPorte S. The Emerging Digital Economy II. U.S. Department of Commerce 1999.
319. Myers JE. Data Modeling for Healthcare Systems Integration: Use of the MetaModel. Metadata.
320. Perficient. Business Intelligence and Analytics for Healthcare. 2014.
321. Analytics H. Clinical Analytics: Can Organizations Maximize Clinical Data? 2010.
322. Healthcare Information and Management Systems Society (HIMSS). Clinical Analytics: Can Organizations Maximize Clinical Data? 2010.
323. LaValle S, Hopkins M, Lesser E, Shockley R, Kruschwitz N. How the smartest organizations are embedding analytics to transform insights into action Massachusetts Institute of Technology IBM Institute for Business Value; 2010.
324. Institute of Medicine (IOM). Crossing the Quality Chasm: A New Health System for the 21st Century. Washington, DC 2001.
325. Ritchie A, Marbury D, Verdon DR, Mazzolini C, Bolyes S. Shifting reimbursement models: The risks and rewards for primary care Medical Economics 2014.
326. Damberg C, Grazier K, Greenfield S, et al. Advancing Physician Performance Measurement Using Administrative Data to Assess Physician Quality and Efficiency: Pacific Business Group on Health; 2005.
327. Scholle SH, Roski J, Dunn DL, et al. Availability of data for measuring physician quality performance. Am J Manag Care 2009;15:67-72.

328. Galvin R, Milstein A. Large employers' new strategies in health care. *N Engl J Med* 2002;347:939-42.
329. Dobbs D, Burkhart T, Halper R, et al. *Clinical & Business Intelligence: Data Management – A Foundation for Analytics Healthcare Information and Management Systems Society (HiMSS)2013.*
330. IBM. What is Data Integration? Data Integration: IBM.com.
331. Kilbridge PM, Classen DC. The informatics opportunities at the intersection of patient safety and clinical informatics. *J Am Med Inform Assoc* 2008;15:397-407.
332. Hoffman G, Molesworth R. *Integrated Data Analytics in an Era of Reform: Ten Observations From the Trenches: eHealth InitiativeTruven Health; 2012.*
333. Lu Z, Su J. Clinical data management: Current status, challenges, and future directions from industry perspectives. *Dove Press Journal - Open Access Journal of Clinical Trials* 2010.
334. Initiative e. *The State of Health Analytics in 2013: Improving Quality and Lowering Costs. McKessen2013.*
335. Gregg H. *Data Analytics: Opportunities and Challenges. Health Information Technology. Becker's Hospital CIO: Asc Communications; 2014.*
336. eHealth Initiative. *The State of Health Analytics in 2013: Improving Quality and Lowering Costs. McKessen2013.*
337. Rudman WJ, Eberhardt JS, Pierce W, Hart-Hester S. Healthcare fraud and abuse. *Perspect Health Inf Manag* 2009;6:1g.
338. Transformation IfHT. *Population Health Management: A Roadmap for Provider-Based Automation in a New Era of Healthcare. Institute for Health Technology Transformation2012.*
339. Crosson K. *Improving Health Care Quality: Fact Sheet. Agency for Healthcare Research and Quality.2002.*
340. Fielding D. *Claims Data ACO: ACOs' Best Source of Patient Health Information. 2013.*
341. Neely A, Adams C, Kennerley M, Prof Andy Neely (Author) CAA, Dr Mike Kennerley (Author). *The Performance Prism: The Scorecard for Measuring and Managing Business Success: The Scorecard for Measuring and Managing Stakeholder Relationships (Financial Times Series): Pearson Education Limited; 2002.*

342. Administration USDoHaHSHRaS. Performance Management and Measurement HRSA2011.
343. *IEEE. Standard Glossary of Software Engineering Terminology*, IEEE Std 729 1983.
344. *IEEE. Standard Glossary of Software Engineering Terminology*, IEEE Std 610.12 1990.
345. HIMSS. The Many Types of Clinical Analytics (Module 3). Healthcare Information and Management Systems Society2014.
346. Dictionary MsM. Patient Day. The Free Dictionary by Farlex. 8 ed. Elsevier2009.
347. Barbuio F. Performance Measurement: A Practical Guide to KPIs and Benchmarking in Public Broadcasters. Commonwealth Broadcasting Association.
348. Williams L. Role of Key Performance Indicators in Successful Business Organizations. Active Garage2011.
349. Sauer DA, McDonald CE, Boshkov L. Errors in Transfusion Medicine. Laboratory Medicine; 2001.
350. Fastman BR, Kaplan HS. Errors in transfusion medicine: have we learned our lesson? Mt Sinai J Med 2011;78:854-64.
351. Kohn LT, Corrigan JM, Donaldson MS. To Err Is Human: Building a Safer Health System: The National Academies Press; 2000.
352. Classen DC, Resar R, Griffin F, et al. 'Global trigger tool' shows that adverse events in hospitals may be ten times greater than previously measured. Health Aff (Millwood) 2011;30:581-9.
353. Stainsby D, Russell J, Cohen H, Lilleyman J. Reducing adverse events in blood transfusion. Br J Haematol 2005;131:8-12.
354. Carayon P, Wood KE. Patient safety - the role of human factors and systems engineering. Stud Health Technol Inform 2010;153:23-46.
355. Adibi H, Khalesi N, Ravaghi H, Jafari M, Jeddian AR. Root-cause analysis of a potentially sentinel transfusion event: lessons for improvement of patient safety. Acta Med Iran 2012;50:624-31.
356. Murphy MFP, Derwood H., Heddle NM. Practical Transfusion Medicine. 4 ed: Wiley-Blackwell; 2013.
357. World Health Organization. Blood transfusion safety2015.

358. Prevention CfDCA. Blood Safety Basics. 2011.
359. Goodman C, Chan S, Collins P, Haught R, Chen YJ. Ensuring blood safety and availability in the US: technological advances, costs, and challenges to payment--final report. *Transfusion* 2003;43:3S-46S.
360. Ness PM. The broken reimbursement system: putting the brakes on the blood safety train. *Transfusion* 2003;43:1S-2S.
361. Liberman A, Rotarius T. A new cost allocation method for hospital-based clinical laboratories and transfusion services: implications for transfusion medicine. *Transfusion* 2005;45:1684-8.
362. The Lewin Group. Ensuring Blood Safety and Availability in the U.S.: Technological Advances, Costs, and Challenges to Payment 2002.
363. Szczepiorkowski ZM, Dunbar NM. Transfusion guidelines: when to transfuse. *Hematology Am Soc Hematol Educ Program* 2013;2013:638-44.
364. Shander A, Javidroozi M, Ozawa S, Hare GMT. What is really dangerous: anaemia or transfusion? *British Journal of Anesthesia* 2011;107:41-59.
365. Carson JL. Transfusion triggers: state of the art in 2010. *Acta Anaesthesiol Belg* 2010;61:145.
366. Pape A, Stein P, Horn O, Habler O. Clinical evidence of blood transfusion effectiveness. *Blood Transfus* 2009;7:250-8.
367. America's Blood Centers. Infectious Risks of Blood Transfusion. . Washington, DC. : Blood Bulletin. America's Blood Centers. ; 2001.
368. America's Blood Centers. Non-infectious Serious Hazards of Transfusion. Blood Bulletin Washington, DC:: America's Blood Centers.; 2002.
369. Maxwell MJ, Wilson MJ. Complications of blood transfusion. *Contin Educ Anaesth Crit Care Pain* 2006;225-9.
370. Kopko PM, Holland PV. Mechanisms of severe transfusion reactions. *Transfusion Clinique et Biologique* 2001;278-81.
371. Prevention CfDCA. Blood Safety. Last Updated 2013.
372. Perrotta PL, Snyder EL. Blood transfusion. *Oxford Textbook of Medicine*: Oxford: Oxford University Press; 2003:791-800.

373. Singh G, Sehgal R. Transfusion-transmitted parasitic infections. *Asian J Transfus Sci* 2010;4:73-7.
374. Yeh SP, Chang CW, Chen JC, et al. A well-designed online transfusion reaction reporting system improves the estimation of transfusion reaction incidence and quality of care in transfusion practice. *Am J Clin Pathol* 2011;136:842-7.
375. AABB, DHHS. Nationwide Blood Collection and Utilization Survey Report. 2007.
376. FDA. Fatalities Reported to FDA Following Blood Collection and Transfusion: Annual Summary for Fiscal Year 2012. Vaccines, Blood & Biologics Updated March 2014.
377. Goodnough LT. Risks of blood transfusion. *Crit Care Med* 2003;31:S678-86.
378. Linden JV, Paul B, Dressler KP. A report of 104 transfusion errors in New York State. *Transfusion* 1992;32:601-6.
379. Klein H, Spahn D, Carson J. Red blood cell transfusion in clinical practice. *Lancet* 2007.
380. Anderson K. Broadening the spectrum of patient groups at risk for transfusion-associated GVHD: implications for universal irradiation of cellular blood components. *Transfusion* 2003;43:1652-4.
381. Skeate RC, Eastlund T. Distinguishing between transfusion related acute lung injury and transfusion associated circulatory overload. *Curr Opin Hematol* 2007;14:682-7.
382. Middelburg RA, van de Watering LM, Briët E, van der Bom JG. Storage time of red blood cells and mortality of transfusion recipients. *Transfus Med Rev* 2013;27:36-43.
383. Triulzi DJ, Yazer MH. Clinical studies of the effect of blood storage on patient outcomes. *Transfus Apher Sci* 2010;43:95-106.
384. van de Watering LM. Effects of red blood cell storage in heavily transfused patients. *Curr Opin Anaesthesiol* 2013;26:204-7.
385. Lelubre C, Vincent JL. Relationship between red cell storage duration and outcomes in adults receiving red cell transfusions: a systematic review. *Crit Care* 2013;17:R66.
386. Fergusson D, Hutton B, Hogan DL, et al. The age of red blood cells in premature infants (ARIP) randomized controlled trial: study design. *Transfus Med Rev* 2009;23:55-61.
387. Lacroix J, Hébert P, Fergusson D, et al. The Age of Blood Evaluation (ABLE) randomized controlled trial: study design. *Transfus Med Rev* 2011;25:197-205.

388. Steiner ME, Assmann SF, Levy JH, et al. Addressing the question of the effect of RBC storage on clinical outcomes: the Red Cell Storage Duration Study (RECESS) (Section 7). *Transfus Apher Sci* 2010;43:107-16.
389. AABB Advancing Transfusion and Cellular Therapies Worldwide (AABB). *Nationwide Blood Collection and Utilization Survey Report* 2007.
390. U.S. Food and Drug Administration. *Fatalities Reported to FDA Following Blood Collection and Transfusion: Annual Summary for Fiscal Year 2013*: U.S. Food and Drug Administration; 2014.
391. Blumberg N. Allogeneic transfusion and infection: economic and clinical implications. *Semin Hematol* 1997;34:34-40.
392. Goodnough LT, Brecher ME, Kanter MH, AuBuchon JP. Transfusion medicine. First of two parts--blood transfusion. *N Engl J Med* 1999;340:438-47.
393. Williamson LM, Lowe S, Love EM, et al. Serious hazards of transfusion (SHOT) initiative: analysis of the first two annual reports. *BMJ* 1999;319:16-9.
394. Sazama K, DeChristopher PJ, Dodd R, et al. Practice parameter for the recognition, management, and prevention of adverse consequences of blood transfusion. College of American Pathologists. *Arch Pathol Lab Med* 2000;124:61-70.
395. Perrotta PL, Snyder EL. Non-infectious complications of transfusion therapy. *Blood Rev* 2001;15:69-83.
396. Klein HG. Allogeneic transfusion risks in the surgical patient. *Am J Surg* 1995;170:21S-6S.
397. Kopko PM, Marshall CS, MacKenzie MR, Holland PV, Popovsky MA. Transfusion-related acute lung injury: report of a clinical look-back investigation. *JAMA* 2002;287:1968-71.
398. Cote C, MacLeod JB, Yip AM, et al. Variation in transfusion rates within a single institution: exploring the effect of differing practice patterns on the likelihood of blood product transfusion in patients undergoing cardiac surgery. *J Thorac Cardiovasc Surg* 2015;149:297-302.
399. Capraro L, Nuutinen L, Myllylä G. Transfusion thresholds in common elective surgical procedures in Finland. *Vox Sang* 2000;78:96-100.
400. Goodnough LT, Soegiarso RW, Birkmeyer JD, Welch HG. Economic impact of inappropriate blood transfusions in coronary artery bypass graft surgery. *Am J Med* 1993;94:509-14.

401. Oddason KE, Gudbjartsson T, Gudmundsson S, Kárasón S, Hreinsson K, Sigurdsson GH. Inappropriate use of blood components in critical care?. *Laeknabladid* 2014;100:11-7.
402. Casina T. References for "Transfusion Medicine Reactions". Advanced Healthcare Network for Laboratory 2014:20.
403. Administration FaD. Fatalities Reported to FDA Following Blood Collection and Transfusion. Washington, DC: Government Printing Office; 2011.
404. Hull RJ, Bray RA, Hillyer C, Swerlick RA. Transfusion-associated chronic cutaneous graft-versus-host disease. *J Am Acad Dermatol* 1995;33:327-32.
405. Silliman CC, Ambruso DR, Boshkov LK. Transfusion-related acute lung injury. *Blood* 2005;105:2266-73.
406. Lichtiger B, Perry-Thornton E. Hemolytic transfusion reactions in oncology patients: experience in a large cancer center. *J Clin Oncol* 1984;2:438-42.
407. Narvios AB, Lichtiger B, Neumann JL. Underreporting of minor transfusion reactions in cancer patients. *MedGenMed* 2004;6:17.
408. Dunne JR, Malone D, Tracy JK, Gannon C, Napolitano LM. Perioperative anemia: an independent risk factor for infection, mortality, and resource utilization in surgery. *J Surg Res* 2002;102:237-44.
409. Taylor RW, O'Brien J, Trottier SJ, et al. Red blood cell transfusions and nosocomial infections in critically ill patients. *Crit Care Med* 2006;34:2302-8.
410. Zallen G, Offner PJ, Moore EE, et al. Age of transfused blood is an independent risk factor for postinjury multiple organ failure. *Am J Surg* 1999;178:570-2.
411. Moore FA, Moore EE, Sauaia A. Blood transfusion. An independent risk factor for postinjury multiple organ failure. *Arch Surg* 1997;132:620-4; discussion 4-5.
412. Corwin HL, Gettinger A, Pearl RG, et al. The CRIT Study: Anemia and blood transfusion in the critically ill--current clinical practice in the United States. *Crit Care Med* 2004;32:39-52.
413. Vamvakas EC, Carven JH. Allogeneic blood transfusion, hospital charges, and length of hospitalization: a study of 487 consecutive patients undergoing colorectal cancer resection. *Arch Pathol Lab Med* 1998;122:145-51.
414. Sharma S, Sharma P, Tyler LN. Transfusion of blood and blood products: indications and complications. *Am Fam Physician* 2011;83:719-24.

415. Goodnough LT, Maggio P, Hadhazy E, et al. Restrictive blood transfusion practices are associated with improved patient outcomes. *Transfusion* 2014.
416. RC A, JS L. Anesthesia in cases of poor risk: Some suggestions for decreasing the risk. *Surg Gynecol Obstet* 1942.
417. Madjdpour C, Spahn DR, Weiskopf RB. Anemia and perioperative red blood cell transfusion: a matter of tolerance. *Crit Care Med* 2006;34:S102-8.
418. Corwin HL. Critical Care Issues For The Nephrologist: Anemia and Red Blood Cell Transfusion in the Critically Ill Seminars in Dialysis 2006;19:513-6.
419. Beattie WS, Karkouti K, Wijeyesundera DN, Tait G. Risk associated with preoperative anemia in noncardiac surgery: a single-center cohort study. *Anesthesiology* 2009;110:574-81.
420. Gajic O, Rana R, Winters JL, et al. Transfusion-related acute lung injury in the critically ill: prospective nested case-control study. *Am J Respir Crit Care Med* 2007;176:886-91.
421. Jawa RS, Anillo S, Kulaylat MN. Transfusion-related acute lung injury. *J Intensive Care Med* 2008;23:109-21.
422. Karp JK. Transfusion-Related Acute Lung Injury (TRALI). CAP Transfusion Medicine Resource Committee NewsPath (Pathology News for Medical Community).
423. Karkouti K, Wijeyesundera DN, Beattie WS, Investigators RBiCSR. Risk associated with preoperative anemia in cardiac surgery: a multicenter cohort study. *Circulation* 2008;117:478-84.
424. Pedersen AB, Mehnert F, Overgaard S, Johnsen SP. Allogeneic blood transfusion and prognosis following total hip replacement: a population-based follow up study. *BMC Musculoskelet Disord* 2009;10:167.
425. Bernard AC, Davenport DL, Chang PK, Vaughan TB, Zwischenberger JB. Intraoperative transfusion of 1 U to 2 U packed red blood cells is associated with increased 30-day mortality, surgical-site infection, pneumonia, and sepsis in general surgery patients. *J Am Coll Surg* 2009;208:931-7, 7.e1-2; discussion 8-9.
426. Ferraris VA, Davenport DL, Saha SP, Austin PC, Zwischenberger JB. Surgical outcomes and transfusion of minimal amounts of blood in the operating room. *Arch Surg* 2012;147:49-55.

427. Castillo JJ, Dalia S, Pascual SK. Association between red blood cell transfusions and development of non-Hodgkin lymphoma: a meta-analysis of observational studies. *Blood* 2010;116:2897-907.
428. Vamvakas EC. Establishing causation in transfusion medicine and related tribulations. *Transfus Med Rev* 2011;25:81-8.
429. Salem-Schatz SR, Avorn J, Soumerai SB. Influence of clinical knowledge, organizational context, and practice style on transfusion decision making. Implications for practice change strategies. *JAMA* 1990;264:476-83.
430. Eder AF, Chambers LA. Noninfectious complications of blood transfusion. *Arch Pathol Lab Med* 2007;131:708-18.
431. Perkins HA, Busch MP. Transfusion-associated infections: 50 years of relentless challenges and remarkable progress. *Transfusion* 2010;50:2080-99.
432. Glance LG, Dick AW, Mukamel DB, et al. Association between intraoperative blood transfusion and mortality and morbidity in patients undergoing noncardiac surgery. *Anesthesiology* 2011;114:283-92.
433. Shander A, Spence RK, Adams D, Shore-Lesserson L, Walawander CA. Timing and incidence of postoperative infections associated with blood transfusion: analysis of 1,489 orthopedic and cardiac surgery patients. *Surg Infect (Larchmt)* 2009;10:277-83.
434. McCullough J. Innovation in transfusion medicine and blood banking: documenting the record in 50 years of TRANSFUSION. *Transfusion* 2010;50:2542-6.
435. Boucher BA, Hannon TJ. Blood management: a primer for clinicians. *Pharmacotherapy* 2007;27:1394-411.
436. Rao SV, Jollis JG, Harrington RA, et al. Relationship of blood transfusion and clinical outcomes in patients with acute coronary syndromes. *JAMA* 2004;292:1555-62.
437. Society for The Advancement of Blood Management. What is blood management?
438. AABB. Patient Blood Management American Association of Blood Banks.
439. Gammon HM, Waters JH, Watt A, Loeb JM, Donini-Lenhoff A. Developing performance measures for patient blood management. *Transfusion* 2011;51:2500-9.
440. Organization WH. Availability, safety and quality of blood products. Sixty-Third World Health Assembly WHA 63.12. 2010.

441. Mbanya D. Barriers and enablers to introducing comprehensive patient blood management in the hospital. *Biologicals* 2012;40:205-8.
442. Gombotz H. Patient Blood Management (PBM): A New Perioperative Transfusion Concept. 2011.
443. Isbister JP. The three-pillar matrix of patient blood management--an overview. *Best Pract Res Clin Anaesthesiol* 2013;27:69-84.
444. Theusinger OM, Kind SL, Seifert B, Borgeat L, Gerber C, Spahn DR. Patient blood management in orthopaedic surgery: a four-year follow-up of transfusion requirements and blood loss from 2008 to 2011 at the Balgrist University Hospital in Zurich, Switzerland. *Blood Transfus* 2014;12:195-203.
445. Isbister JP. The three-pillar matrix of patient blood management – An overview. In: setting. *Sociattpopbmitp-o*, ed. *Best Practice & Research Clinical Anaesthesiology* 2013.
446. Shander A, Goodnough L. Blood transfusion as a quality indicator in cardiac surgery. *Journal of American Medical Association* 2010;1610-1.
447. The Joint Commission. Inspiring health care excellence. 2014.
448. Lucas MT. Joint Commission Blood Management Performance Measures. jointcommission.org 2011.
449. Knowles W. The Benefits of Patient Blood Management. *Hospitals and Health Networks* 2014.
450. Commission J. Implementation Guide for The Joint Commission Patient Blood Management Performance Measures. 2011.
451. The Joint Commission. Implementation Guide for The Joint Commission Patient Blood Management Performance Measures 2011.
452. Haemonetics: The Blood Management Company. Actionable Data for Measureable Results. *BraintrBraintree, MA: Haemonetics Corporation; 2010.*
453. Friedman B. Improving Blood Transfusion Hemoglobin Level an Inadeqate Metric: *Lab Soft; 2014.*
454. Institute of Medicine. The Promise of Health Information Technologies. Washington, DC: Institute of Medicine,; 2008.
455. Hayward R. Information Technology Tools to Support Best Practices in Healthcare: 2007 IOM Annual Meeting Summary. Washington, DC: Institute of Medicine; 2007.

- 456. Kania-Lachance DM, Best PJ, McDonah MR, Ghosh AK. Evidence-based practice and the nurse practitioner. *Nurse Pract* 2006;31:46-54.
- 457. Jette DU, Bacon K, Batty C, et al. Evidence-based practice: beliefs, attitudes, knowledge, and behaviors of physical therapists. *Phys Ther* 2003;83:786-805.
- 458. Paul RW. *Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World* 2ed: Foundation for Critical Thinki; 1993.
- 459. Rodrigues RJ. Information systems: the key to evidence-based health practice. *Bull World Health Organ* 2000;78:1344-51.
- 460. Zvárová J. On the medical informatics structure. *International Journal of Medical Informatics* 1997;4:75-81.
- 461. Dickinson E. Clinical effectiveness for health care quality improvement. *J Qual Clin Pract* 1998;18:37-46.
- 462. Michelsen K, Brand H, Achterberg P, Wilkinson J. Promoting better integration of health information systems: best practices and challenges: World Health Organization Europe; 2015.
- 463. Advancing Transfusion and Cellular Therapies Worldwide (AABB). Patient Blood Management American Association of Blood Banks.
- 464. Mukhtar SA, Leahy MF, Koay K, et al. Effectiveness of a patient blood management data system in monitoring blood use in Western Australia. *Anaesth Intensive Care* 2013;41:207-15.
- 465. Frank SM, Savage WJ, Rothschild JA, et al. Variability in blood and blood component utilization as assessed by an anesthesia information management system. *Anesthesiology* 2012;117:99-106.
- 466. Leach MJ. Evidence-based practice: a framework for clinical practice and research design. *Int J Nurs Pract* 2006;12:248-51.
- 467. Houser J, Oman KS. *Evidence-Based Practice: An Implementation Guide for Healthcare Organizations*. 1st ed. Sudbury, MA: Jones & Bartlett Learning; 2011.
- 468. Pagoto SL, Spring B, Coups EJ, Mulvaney S, Coutu MF, Ozakinci G. Barriers and facilitators of evidence-based practice perceived by behavioral science health professionals. *J Clin Psychol* 2007;63:695-705.
- 469. Public Health Foundation. *From Silos to Systems: Using Performance*

- Management to Improve the Public's Health. Performance Management National Excellence Collaborative. Seattle, Washington: TurningPoint.
470. Doyle J, Gaston M, Nyquist P, Seredynski G, Skulmoski J, Carson J. Guide For Developing Relevant Key Performance Indicators For Public Sector Reporting 2010.
 471. Welfare AIOHA. A guide to data development. Australian Institute of Health and Welfare (AIHW)2007. Report No.: AIHW Cat. no. HWI 94.
 472. Authority HlaQ. Guidance on Developing Key Performance Indicators and Minimum Data Sets to Monitor Healthcare Quality Health Information and Quality Authority2013.
 473. McLoughlin V, Leatherman S, Fletcher M, Owen J. Improving performances using indicators. Recent experiences in the United States, United Kingdom and Australia.:International Journal for Quality in Health Care; 2009:455-62.
 474. Commission H. The Better Metrics project. Healthcare Commission2008.
 475. Tanenbaum SJ. Improving the quality of medical care: the normativity of evidence-based performance standards. Theor Med Bioeth 2012;33:263-77.
 476. South SF, Hegarty JAS. Using Lean to Identify Process Improvement Opportunities and Improve Effectiveness of Transfusion Professionals. Clinical Diagnostics: Johnson & Johnson Company; 2010.
 477. Nerenz DR, Neil N. Performance Measures for Health Care Systems: Center for Health Management Research; 2001.
 478. Australian Institute Of Health and Welfare. A guide to data development. Australian Institute of Health and Welfare (AIHW)2007. Report No.: AIHW Cat. no. HWI 94.
 479. Health Information and Quality Authority. Guidance on Developing Key Performance Indicators and Minimum Data Sets to Monitor Healthcare Quality Health Information and Quality Authority2013.
 480. Commission TJ. Attributes of Core Performance Measures And Associated Evaluation Criteria. The Joint Commission2010.
 481. Organization WH. Mental Health Information Systems. World Health Organization2005.
 482. Council NHaMR. A guide to the development, implementation, and evaluation of clinical practice guidelines. Australia: National Health and Medical Research Council 1999.

483. HR R, Pronovost P, Diette G. From a process of care to a measure: the development and testing of a quality indicator. *International Journal for Quality in Health Care*. *International Journal for Quality in Health Care* 2001;489-96.
484. Trochim WM. Types of Reliability. *Research Method Knowledge Base* 2006.
485. Mainz J. Developing evidence-based clinical indicators: a state of the art methods primer. *International Journal for Quality in Health Care*. *International Journal for Quality in Health Care* 2003.
486. Campbell S, Braspenning J, Hutchinson A, Marshall M. Research methods used in developing and applying quality indicators in primary care. . *Quality and Safety. Quality and Safety* 2002;358-64.
487. Ezekwe N. *Petroleum Reservoir Engineering Practice*: Pearson Education Inc.; 2011.
488. Commission. A. *On Target: the practice of performance indicators*. Commission for Local Authorities and the National Health Service in England and Wales. Commission for Local Authorities and the National Health Service in England and Wales 2000.
489. AuBuchon JP, Puca K, Saxena S, Shulman IA, Waters JH. *Getting Started in Patient Blood Management*. Bethesda, MD: Advancing Transfusion and Cellular Therapies Worldwide (AABB); 2011.
490. Brockopp D, Schreiber J, Hill K, Altpeter T, Moe K, Merritt S. A successful evidence-based practice model in an acute care setting. *Oncol Nurs Forum* 2011;38:509-11.
491. Evidence-Based Medicine Working Group. Evidence-based medicine. A new approach to teaching the practice of medicine. *JAMA* 1992;268:2420-5.
492. Kitson A, Harvey G, McCormack B. Enabling the implementation of evidence based practice: a conceptual framework. *Qual Health Care* 1998;7:149-58.
493. McInerney P, Suleman F. Exploring knowledge, attitudes, and barriers toward the use of evidence-based practice amongst academic health care practitioners in their teaching in a South African university: a pilot study. *Worldviews Evid Based Nurs* 2010;7:90-7.
494. White B. Making evidence-based medicine doable in everyday practice. *Fam Pract Manag* 2004;11:51-8.
495. Shorr AF, Duh MS, Kelly KM, Kollef MH, Group CS. Red blood cell transfusion and ventilator-associated pneumonia: A potential link? *Crit Care Med* 2004;32:666-74.

- 496. Taylor RW, Manganaro L, O'Brien J, Trottier SJ, Parkar N, Veremakis C. Impact of allogenic packed red blood cell transfusion on nosocomial infection rates in the critically ill patient. *Crit Care Med* 2002;30:2249-54.
- 497. Shorr AF, Jackson WL. Transfusion practice and nosocomial infection: assessing the evidence. *Curr Opin Crit Care* 2005;11:468-72.
- 498. Hannon T. The bloody truth: 10 facts about blood transfusions everyone should know. *MLO: Medical Laboratory Observer* 2010.

Appendices

Appendix A: Bloodcenter of Wisconsin 2011 Adult Blood Utilization Review Guidelines

BloodCenter of Wisconsin

**2011 ADULT BLOOD UTILIZATION
REVIEW GUIDELINES**

Approved by BloodCenter of Wisconsin Medical Advisory Committee on 4/22/2011
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Appendix B: Patient Blood Management Newsletters

Blood Management and Wheaton Franciscan Health Care

Wheaton Franciscan Healthcare (WFHC) and BloodCenter of Wisconsin (BCW) have collaborated in a program called *TxMD™*. *TxMD* is comprised of various initiatives designed to facilitate transformational changes throughout transfusion medicine practice. These initiatives include Patient Blood Management (PBM).

What is Patient Blood Management?

PBM emphasizes strategies and techniques to optimize blood transfusion practice in a variety of ways including strategies to decrease blood loss and enhance a patient's own blood supply.

What will *TxMD™* do for WFHC?

TxMD initiatives will help to standardize practice, reduce cost, and improve patient outcomes.

Why participate in *TxMD™*?

There is growing evidence that patient blood management can improve patient outcomes by utilizing fewer transfusions. An evidenced-based trial in critical care, conducted by Hebert and colleagues, showed that patients can tolerate lower levels of hemoglobin and have better outcomes with fewer transfusions.

What are the goals of *TxMD™* at WFHC?

The goal for *TxMD* is to promote the safe, optimal use of all blood products, monitor transfusion practices with data to physicians and provide ongoing education to all caregivers and patients who receive blood products.

Learn more about blood product indications and current literature findings:

- Go to www.beLearning.bcw.edu
- Create user name and password
- Select 'To Transfuse or Not to Transfuse'

Patient Blood Management Strategies

Optimize Your Patient	Minimize Blood Loss	Adopt Best Practices
<ul style="list-style-type: none"> Identify & correct anemia Assess & treat bleeding disorders Review prescription & over the counter medications that may increase patient's bleeding risk Engage patient in treatment plan 	<ul style="list-style-type: none"> Control surgical bleeding with intraoperative techniques & fluid management Consider blood salvage/ blood recovery Utilize pharmacological agents to maintain hemostasis Reduce frequency of lab testing & minimize sample volumes 	<ul style="list-style-type: none"> Follow restrictive transfusion thresholds based on clinical signs & symptoms Give one unit of RBC then reassess Transfuse plasma & platelets per evidence-based guidelines

Hebert P, Wells G, et al. A Multicentered, Randomized, Controlled Clinical Trial of Transfusion Requirements in Critical Care. *N Engl J Med.* 1999; 340(6): 409-417.

Carson J, Terrin M, et al. Liberal or Restrictive Transfusion in High-Risk Patients After Hip Surgery. *N Engl J Med.* 2011;365:2453-2462.

If you have questions please contact Dr. Kathy Puca, Medical Director, BloodCenter of Wisconsin, kathleen.puca@bcw.edu or Nanci Fredrich, RN, Transfusion Safety & Blood Management Officer, nanci.fredrich@bcw.edu

Be SINGLE minded

Patient Blood Management

With today's decreasing donor population and increasing transfusion costs, adopting blood management practices that focus on the patient is beneficial to both the hospital and the blood center. A best-practice strategy when ordering RBC transfusions for the non-bleeding patient is to perform a single transfusion then reassess to determine if a second unit is needed.

History of RBC Ordering Practice

Historically, transfusion practice has been based on tradition rather than science. In the past, when physicians ordered a single RBC unit for transfusion, questions were raised: Was it necessary? Did the one RBC unit provide significant benefit? Physicians were scrutinized for ordering one unit. To avoid this, physicians developed a standard practice of ordering two units for the transfusion event.

When should single RBC units be transfused?

Single-unit RBC transfusions should be considered in a symptomatic, clinically stable patient with an Hgb < 7g/dL who is not actively bleeding.¹ Changing to a single-unit RBC-ordering strategy can result in reduction of blood use, and is not associated

with increased risk for patients.² However, transfusion needs should always be assessed on an individual patient basis.

Transfuse ONE RBC unit – then reassess.

Why change to single unit RBC transfusions?

Research has been published to indicate that blood transfusions, in both surgical and medical patients, have been linked to longer hospital stays and higher incidence of various complications, including infections.^{3,4} There is evidence to support a relationship between units transfused and these adverse events: the higher the number of RBC transfusions a patient receives, the higher the risk of acquiring a post-op infection.³

How effective is a single unit transfusion?

- On average, a single unit of RBCs will raise the Hgb 1 g/dL in a non-bleeding patient.
- Treat individual patient signs and symptoms, not laboratory values alone.
- Reassess the patient's signs, symptoms and response to the first unit before considering a second unit of RBCs.

1. Carson JL, Grossman BJ, et al. Red Blood Cell Transfusion: A Clinical Practice Guideline from the AABB. *Ann Intern Med.* 2012; 157: 49-58.
2. Berger M, Gerber B, et al. Significant Reduction of Red Blood Cell Transfusion Requirements by Changing from Double Unit to a Single Unit Transfusion Policy in Patients Receiving Intensive Chemotherapy or Stem Cell Transplantation. *Haematologica.* 2012; 97(1):116-122.
3. Shorr A, Jackson W, et al. Transfusion Practice and Blood Stream Infections in Critically Ill Patients. *Chest.* 2005; 127:1722-1728.
4. Hebert P, Wells G, et al. A Multicentered, Randomized, Controlled Clinical Trial of Transfusion Requirements in Critical Care. *N Engl J Med.* 1999; 340(6): 409-417.

Did You Know?

A blood transfusion can be thought of as a "liquid transplant". Learn more about blood product indications and current literature findings:

- Go to www.beLearning.bcw.edu
- Create user name and password
- Select "To Transfuse or Not to Transfuse"

If you have questions please contact Dr. Kathy Puca, Medical Director, BloodCenter of Wisconsin, kathleen.puca@bcw.edu or Nanci Fredrich, RN, Transfusion Safety & Blood Management Officer, nanci.fredrich@bcw.edu

Curriculum Vitae

Nazanin Tabesh

College of Engineering and Applied Science
University of Wisconsin-Milwaukee, Milwaukee, WI

Education

2011 – 2015 **Ph.D. in Biomedical and Health Informatics**, College of Engineering and Applied Science, University of Wisconsin-Milwaukee, Milwaukee, WI.
Emphasis in Health Information Systems

Advisors:

Timothy Patrick, Ph.D., Sandra Butschli, B.Sc., Gary Ross, Ph.D., Priya Nambisan, Ph.D., Zhihui Luo, Ph.D., Brian Wroblewski, MBA, M.S., Aaron Buseh, Ph.D., MPH, MSN

Ph.D. Dissertation Research – From Data to Decision: An Implementation Model for the Use of Evidence-Based Medicine, Data Analytics, and Education in Transfusion Medicine Practice.

2008 – 2010 **M.Sc. in Clinical Laboratory Science**, College of Health Sciences University of Wisconsin-Milwaukee, Milwaukee, WI.
Emphasis in Microbiology and Immunology

Advisors:

Marcia A. Firmani Ph.D., MSPH, Jerri-Anne Lyons Ph.D., Anthony A. Azenabor, Ph.D., C.S. (ASCP),

M.S. Thesis Research – Comparison of Fitness among Drug-Resistant and Drug-Susceptible *Mycobacterium tuberculosis* Clinical Isolates from Wisconsin: Survival and Cytokine Production in Human Macrophages.

2002 – 2006 **B.Sc. in Biological Sciences**, College of Art and Sciences, Marquette University, Milwaukee, WI.
Minor in Chemistry

Professional Experience

Application

2013 - Present **Systems Analyst**, Dept. of Information Services, BloodCenter of Wisconsin, Milwaukee, WI.

Define, design, implement, and support information technology and informatics solutions that meet the information and data management needs of clinical and research stakeholders.

2011 – 2013 **EMR Implementation Analyst**, Norris Health Center, University of Wisconsin-Milwaukee, Milwaukee, WI

Defined, designed, and implemented processes to facilitate the transition of Norris Health Center from a paper-based clinic to an electronic medical record clinic.

Research

2012 – 2015 **Research Associate**, Dept. of Biomedical and Health Informatics, College of Engineering and Applied Sciences and College of Health Sciences, University of Wisconsin – Milwaukee, Milwaukee, WI; and Dept. of Information Services, BloodCenter of Wisconsin, Milwaukee, WI.

Ph.D. Dissertation Research – From Data to Decision: An Implementation Model for the Use of Evidence-Based Medicine, Data Analytics, and Education in Transfusion Medicine Practice.

Other Research – Development and use of an analytics framework in Patient Blood Management as a feedback mechanism to evaluate changes and assess the sustainability of the changes in physicians' practice.

2011 – 2012 **Research Associate**, Dept. of Human Molecular Genetic Center and Dept. of Biotechnology Bioengineering, Center for Computational Medicine, Medical College of Wisconsin, Milwaukee, WI.

Research – Multiscale Modeling and Data Integration in the Virtual Physiological Rat Project.

2009 – 2010 **Research Assistant**, Dept. of Clinical Laboratory Science, College of Health Sciences, University of Wisconsin – Milwaukee, Milwaukee, WI.

M.S. Thesis Research – Comparison of Fitness among Drug-Resistant and Drug-Susceptible *Mycobacterium tuberculosis* Clinical Isolates from Wisconsin: Survival and Cytokine Production in Human Macrophages.

Other Research – A 10-year retrospective analysis of tuberculosis in the greater Milwaukee area.

2007 – 2009 **Research Technologist**, Dept. of Human Molecular Genetics Center and Dept. of Biotechnology Bioengineering, Medical College of Wisconsin, Milwaukee, WI.

Research – Multifunctional and High-Throughput Physiological Profiling of Engineered Heart Tissue for Drug Development.

Teaching

2010 **Teaching Assistant**, Dept. of Clinical Laboratory Science, College of Health Sciences, University of Wisconsin – Milwaukee, Milwaukee, WI

Molecular and Genetic Diagnostics Laboratory Course (Winterim Session).

2008 **Instructor**, Dept. of Clinical Laboratory Science, College of Health Sciences, University of Wisconsin – Milwaukee, Milwaukee, WI

Course Titled: Techniques in Biomedical Sciences Laboratory (Summer Session). Coordinated and taught techniques in biomedical sciences laboratory course to high school students' in junior/senior level standing. Duties included: preparing lectures and discussions, demonstrations, and practical's; lecturing and answering questions; correcting and grading homework and lab reports.

2003 – 2004 **Academic Tutor**, Marquette University, Milwaukee, WI.
Courses included: biology, general chemistry, general chemistry lab, and biochemistry.
Duties included teaching lecture and reviewing homework materials, answering questions.

Membership

2013 - Present AABB (American Association of Blood Banks)
Student Member

2013 - Present MBAA (Midwest Business Administration Association)
Student Member

2012 - Present HIMMS (Healthcare Information and Management Systems Society)
Student Member

2011 - Present AMIA (American Medical Informatics Association)
Student Member

2011 - Present Healthcare Leadership Forum
Student Member

Conference Attendance

2015	AMIA 2015 Annual Symposium, San Francisco, CA. (Student stipend award winner)
2015	AABB 2015 Annual Meeting, Anaheim, CA.
2015	HIMMS Wisconsin Dairyland Chapter 2015 Annual Spring Leadership Conference, Waukesha, Wisconsin.
2015	Healthcare Leadership Forum: What Are Employers Considering to Address Healthcare Costs Over the Next Five Years? Milwaukee, WI.
2014	AMIA 2014 Annual Symposium, Washington, DC. (Student stipend award winner)
2014	2014 MBAA International Conference, Chicago, IL.
2014	2014 Leadership Healthcare Forum: <i>Leveraging Evidence Across the Care Continuum!</i> Chicago, IL.
2013	AMIA 2013 Annual Symposium, Washington, DC. (Student stipend award winner)
2013	<i>2013 Leadership Healthcare Forum:</i> Healthcare Reform: What the healthcare industry should be doing now? Milwaukee, WI.
2012	AMIA 2012 Annual Symposium, Washington, DC. (Student stipend award winner)
2011	AMIA 2011 Annual Symposium, Chicago, IL. (Student stipend award winner)

Publications and Poster Presentations

Publications:

Daniel A. Beard, Maxwell L. Neal, **Nazanin Tabesh-Saleki**, Christopher T. Thompson, Mary Shimoyama and Brian E. Carlson. Multi-scale Modeling and Data Integration in the Virtual Physiological Rat Project. Annals of Biomedical Engineering **2012** (DOI: 10.1007/s10439-012-0611-7).

Conference Proceedings:

Nazanin Tabesh, Mary E. Herwig, Julie F. DeLisle, Sandra J. Butschli. Analytics Framework: The Missing Piece to Patient Blood Management. (**Oral Presentation**). In: AABB 2015 Annual Meeting, Anaheim, CA. October **2015**.

Nazanin Tabesh, Julie F. DeLisle, Jean Shelby, Debora Oseland, Daniel B. Ross, Kathleen E. Puca. Impact of Individual Physician Blood Reports and “1 vs. 2 unit” Metric to Lower RBC Transfusions. (**Oral Presentation**, Abstract # P31) In: Proceeding of the NATA 16th Annual Symposium, Prague, Czech Republic. April **2015**.

Nazanin Tabesh-Saleki, Mary E. Herwig, Julie F. DeLisle, Nanci L. Fredrich, Sandra J. Butschli, Timothy B. Patrick, and Kathleen E. Puca. Bridging the Gap in Knowledge and Practice: from Data to Decision. (**Poster Presentation**) In: Proceeding of the American Medical Informatics Association 2014 Annual Symposium, Washington, DC. November **2014**.

Nazanin Tabesh-Saleki, Brian E. Carlson, Christopher T. Thompson, Maxwell Neal, Daniel L. Cook, and Mary Shimoyama. Innovative Use of Ontologies: Association of Physiological Pathways to Corresponding Computational Models and Disparate Data Types. (**Poster Presentation**) In: Proceeding of the American Medical Informatics Association 2013 Annual Symposium, Washington, DC. November **2013**.

Nazanin Tabesh-Saleki, Mary Anne Wawrzyn, and Timothy Patrick. Managing Ambiguity and Continuity: A Two-Year Summary of the UWM EMR Practicum. (**Poster Presentation**) In: Proceeding of the American Medical Informatics Association 2013 Annual Symposium, Washington, DC. November **2013**.

Nazanin Tabesh-Saleki, Brian E. Carlson, Christopher T. Thompson, Daniel A. Beard, and Mary Shimoyama. Making Computational Models Accessible through Ontologies and Visualization Tools. (**Poster Presentation**) In: Proceeding of the American Medical Informatics Association 2012 Annual Symposium, Washington, DC. November **2012**.

Nazanin Tabesh-Saleki, Rami W. Owais, Zubair Dhala, Maryanne Wawrzyn, and Timothy Patrick, **2012**. EMR Practicum-II at University of Wisconsin-Milwaukee: Transition of Norris Health Center from Paper Forms to EMR. (**Poster Presentation**) In: Proceeding of the American Medical Informatics Association 2013 Annual Symposium, Washington, DC. November **2012**.

Eric Dohman, **Nazanin Tabesh-Saleki**, Natalie Rahming, Colleen Lindell, and Timothy Patrick. EMR Practicum I at University of Wisconsin-Milwaukee. (Poster Presentation) In: Proceeding of the American Medical Informatics Association 2013 Annual Symposium, Chicago, IL. November **2011**.

Nazanin Tabesh-Saleki, Bryan Mounce, and Marcia Firmani. Comparison of fitness among drug-resistant and drug-susceptible *Mycobacterium tuberculosis* clinical isolates. (Poster Presentation) 110th General Meeting of the American Society of Microbiology, San Diego, CA **2010**.

Vy Lam, **Nazanin Tabesh**, Anesa Badic, Matthew Staniszewski, and Tetsuro Wakatsuki*. **2009**. Multifunctional and High-Throughput Physiological Profiling of Engineered Heart Tissue for Drug Development. In: Proceeding of XXXVI International Congress of Physiological Sciences (IUPS2009) Function of Life: Elements and Integration, Kyoto, Japan. August – **2009**. Poster # P1PM-4-3.

Grants and Funding

NIH/NHLBI R15-HL092628-01A1

Academic Research Enhancement Award for project titled, “*Mycobacterium tuberculosis*: reactive oxygen and nitrogen intermediate resistance.” **Firmani** (PI) **Tabesh-Saleki** (Research Assistant)

University of Wisconsin-Milwaukee College of Health Sciences Student Research Grant Award

CHS Student Research Grant Award project titled, “A comparison of survival among drug-resistant and drug-susceptible *Mycobacterium tuberculosis* within activated macrophages.” **Nazanin Tabesh-Saleki**.

Honors and Awards

- | | |
|------|--|
| 2014 | College of Engineering and Applied Science Dean’s Scholarship Award. University of Wisconsin-Milwaukee, Milwaukee, WI. |
| 2013 | College of Engineering and Applied Science Dean’s Scholarship Award. University of Wisconsin-Milwaukee, Milwaukee, WI. |
| 2011 | The Chancellor's Golda Meir Library Scholar Award. College of Engineering and Applied Science, University of Wisconsin – Milwaukee, Milwaukee, WI. |
| 2010 | Scientific Research Symposium 3 rd Place Award. College of Health Sciences, University of Wisconsin-Milwaukee, Milwaukee, WI. |

Volunteer Experience

2012 - Present Clinical and Translational Science Institute (CTSI) Southeastern Wisconsin Regional Collaboration. Milwaukee, WI.

Regional biomedical collaboration involving clinical and translational science between Marquette University, the Medical College of Wisconsin, UW-Milwaukee, the Milwaukee School of Engineering, the BloodCenter of Wisconsin, Children's Hospital, and Froedtert Hospital.

The CTSI collaboration will advocate, facilitate, and foster the continuum of research from bench to bedside to community practice.

2011 – 2013 Non-Academic Misconduct Committee, University of Wisconsin – Milwaukee. Milwaukee, WI.

2010 Student representative on a new faculty Search and Screen Committee, College of Health Sciences, University of Wisconsin-Milwaukee, Milwaukee, WI.