Visual analytical tool for evaluation of 10-year perioperative transfusion practice at a children’s hospital

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ABSTRACT
Children are a vulnerable population in the operating room, and are particularly at risk of complications from unanticipated hemorrhage. The decision to prepare blood products prior to surgery varies depending on the personal experience of the clinician caring for the patient. We present the first application of a data visualization technique to study large datasets in the context of blood product transfusions at a tertiary pediatric hospital. The visual analytical interface allows real-time interaction with datasets from 230,000 procedure records. Clinicians can use the visual analytical interface to analyze blood product usage based on procedure- and patient-specific factors, and then use that information to guide policies for ordering blood products.

BACKGROUND AND SIGNIFICANCE
Timely ordering and administration of blood products during surgery can be critical and life saving for children; however, blood products are a limited resource worldwide. Clinicians traditionally use approaches such as a maximum surgical blood order schedule (MSBOS) to guide decisions to order blood products for a procedure.1 MSBOS policies are rare in pediatrics primarily because smaller volumes of blood products are required. In the USA, increased use of blood products has resulted in smaller blood product supply pools and more frequent shortages, with negative consequences.2 For instance, blood product shortages forced the cancelation of elective surgical cases in 12% of hospitals across the USA in 2001, and delay of availability of blood products has been linked to death.2,3 Thus clinicians must anticipate the need for blood products for children undergoing surgical procedures, so that they are available for patients at high risk of hemorrhage and to minimize unnecessary orders for blood products in low-risk procedures.6

Clinicians need data-driven decision support to identify children at high risk of surgery-induced hemorrhage and anticipate the potential need for transfusion. Electronic health records (EHRs) have been shown to provide a foundation for analytical models that reliably assess actual transfusion.10 Most EHRs now have an electronic interface to analyze blood product usage, allowing real-time interaction with datasets from 230,000 procedure records. Clinicians can use the visual analytical interface to analyze blood product usage based on procedure- and patient-specific factors, and then use that information to guide policies for ordering blood products.

MATERIALS AND METHODS
The Institutional Review Board at The Children’s Hospital of Philadelphia approved this study. The anesthesia information management system (AIMS) (CompuRecord; Phillips, Andover, Massachusetts, USA) data warehouse and the blood bank database (BB) (MEDITECH, Westwood, Massachusetts, USA) were queried for anesthesia and blood transfusion records dated from October 1, 2001 to December 31, 2010. This includes patients throughout the entire hospital, ranging from premature newborns to adults with congenital conditions and obstetric patients with high-risk fetuses. All of the records for patients satisfying the inclusion criteria were retrieved for analysis. Patients who received blood products during surgery were identified from the AIMS records, and then cross-referenced to the BB records to identify patients who had blood products prepared within 72 h of surgery. The exclusion criteria involved any patients in the study period who did not have a procedure documented in the AIMS database.

We retrieved each patient’s age, weight, date of birth, service date, gender, procedure timestamps, American Society of Anesthesiologists (ASA) Physical Status,13 pre-defined surgical procedure categories, International Classification of Disease (ICD-9), Current Procedural Terminology (CPT-4) and case length in minutes, International Classification of Disease (ICD-9), Current Procedural Terminology (CPT-4) and case length in minutes. We categorized ICD-9 codes using the Clinical Classification Software developed by the Agency for Healthcare Research and Quality (AHRQ).14 The CPT-4 codes were referenced with cross-walks developed by the ASA.15 Patient subcategories were created for each of the demographic variables. The user interface allows
The blood product data included the following categories: packed red blood cells, fresh-frozen plasma, platelets, cryoprecipitate, fresh whole blood, and reconstituted blood. The resulting measure of volume/Ve is the sum of volumes for packed red blood cells, reconstituted blood, and fresh whole blood. The aggregate measurement consisted of the patient mass (mL/kg) of blood product transfused. The aforementioned databases were combined, cleansed, pre-processed, and reduced to a dimensional model. The aggregated volume of blood products transfused was used to explore data relationships and types. Finally, we took advantage of the associative in-memory engine represented by the graphical user interface in Qlikview (QlikTech, Radnor, Pennsylvania, USA). A graphical user interface (Qlikview, QlikTech, Radnor, Pennsylvania, USA) was designed to allow the exploration and identification of outliers of the study variables through the use of detection of outliers, correlations, and data distributions, and the trends, patterns, and data classifications. The graphs were used to display categorical data and nominal, ordinal, and interval variables, while scatter plots were used to explore data relationships and types. The data was organized into the model using variables that exist in every data set.
be applied using the analytical tool and are reflected on the graphs and histograms.

Data validation
Two reviewers validated the accuracy of the database records during the data exploration phase and reviewed the following patient variables: age, weight, case length, ASA physical status, blood product categories, procedure category, and ICD-9 and CPT-4 codes. Manual chart review was performed to investigate the outliers that were identified during analysis of the transfusion histograms. For example, figure 2 depicts the frequency histogram of the ages (in days) of patients who received blood transfusions. The ages of 79 patients were identified as >60 years; 77 patients were >100 years old. The correct ages of the outliers were determined by comparing each patient’s date of birth with the date of the procedure. When applicable, the analytical database was updated with the correct information, although the original data were preserved for further reference. For each variable, >0.1% of the records were associated with possible data entry errors or missing values. Records that were identified as erroneous or could not be corrected were excluded from the analytical database; 84 records were excluded in this fashion.

Clinical use cases
After developing and validating the analytical dataset, we developed the user interface shown in figure 2. The broad procedure category filters were applied to evaluate the distribution of blood product transfusions within each age category. An example display shown in table 2 gives the surgery categories associated with the highest number of cases requiring blood products for the 0–1 month age group.

The interface allows clinicians preparing for a procedure to rapidly determine the historical frequency of blood product utilization during specific procedures, and then customize the transfusion data by age, weight, ASA physical status, and comorbidities. For example, an anesthesiologist preparing for a nephrectomy in a 1–3-year-old patient can rapidly determine that the historical frequency of blood product utilization was 13.4%, and the mean (SD) blood product requirement was 11 (3.3) mL/kg packed red blood cells. A use-case scenario based on neonatal excision of a sacrococcygeal teratoma is displayed in figure 3.

DISCUSSION
In this study, we demonstrated the first reported use of a visual analytical interactive tool for evaluating comprehensive transfusion practice in a pediatric hospital. EHR database analysis to develop an MSBOS has been previously applied in an adult surgical setting. Although that study evaluated blood product use by type of surgical procedure and intraoperative transfusion requirements, it excluded patients under 18 years of age. Pediatric patients were excluded because of variable blood product requirements, which in children are routinely
determined in volume per body mass (mL/kg). Keung et al. described transfusion requirements in a pediatric cohort, but limited the evaluation to packed red blood cells used in the perioperative period. Both of these studies focused their analysis on the absolute number of packed red blood cell units used, and omitted other blood product components.

There are several limitations to our study related to the inherent data quality issues that can arise when using administrative...
First, this visual analytical tool draws from a clinical data warehouse, which incorporates data from several sources that require subject-matter expertise to interpret. The process to identify procedures relied on CPT-4 codes to establish subgroups of procedures. The CPT-4 codes were organized into subgroups with hierarchical crosswalk tools such as the ASA 2012 Crosswalk and the AHRQ Clinical Classification Software Tool.16 17 However, the procedure codes reflect the reported billing data, which may not reflect the comprehensive details found in the medical history and procedure notes.

Second, manual data entry errors in the anesthesia record (eg, volume and type of blood product being transfused) were unavoidable. These values were cross-checked against the BB, which is the gold standard for transfusion records. These data are validated at the time of data entry by two-person verification during blood product labeling, release from blood bank, and administration to the patient. There is a very low likelihood of error in the number of units administered, and a higher chance of error for the volume issued versus the volume transfused. The latter error is not clinically important because the pre-procedure orders are mostly based on units of blood rather than a specific volume or fraction of a unit. Despite the potential for data entry errors regarding blood volumes administered, the database can identify procedures where blood product administration occurred. Our ultimate goal is to identify procedures where we can anticipate the need to order blood products, and, if so, how many units are indicated.

The concept of applying decision support to blood product ordering is well described. The MSBOS approach, originally developed by Friedman, defined a list of surgical procedures with specific recommendations for blood product allocation.1 This approach has been applied in various settings, ranging from subspecialty specific to generalized recommendations.18 21 However, application of MSBOS in pediatric hospitals is not widespread, and is typically limited to subsets of procedures that routinely use blood transfusions, such as cardiovascular procedures. To date, there are no reports of data-driven MSBOS systems for pediatric populations. Our approach offers the advantage of dynamic, patient-specific decision support. In addition, the visual analytical tool enables the enterprise-scale evaluation of transfusion practice, and can assist in the development of institutional MSBOS policies and guidelines.7 8 22

In summary, the visual analytical interface we designed enables clinicians to perform rapid analysis of the historical transfusion practices across procedures and age groups. This is the first reported use of an interactive visual analytical tool specifically designed to study perioperative transfusion practice in a large surgical cohort in a free-standing children’s hospital. Clinicians are able to navigate the database in real time to gain understanding of actual practice to guide decisions for similar patients. Future work will determine if accessing these data can improve blood product allocation by ensuring that high-risk patients have blood products available while reducing unnecessary blood tests for low-risk patients. Integration of this data visualization tool with the EHR will allow near-real-time evaluation of evolving transfusion trends in the institution as a quality outcome metric.

It is our goal to use this platform to enhance blood use management and standardize transfusion practices at our institution. As a part of this process, we plan to evaluate the tool in the development of policies for blood product recommendations with expert panels at our institution. Furthermore, any changes in practice will be evaluated by monitoring transfusion practice and blood product availability prior to the procedure.

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Competing interests None.

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**Data sharing statement** The database contains information that could potentially be used to identify patients. As such, we are not making the current database accessible to the public. The cross-walks we used for this database are accessible via the Agency for Healthcare Quality Improvement and will not be duplicated here.

**REFERENCES**