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.[2–5] 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 requirements.[7–10] While a data-driven MSBOS tool has been described previously, that study excluded patients younger than 18 years old because of the wide variations in total volume of blood products transfused in pediatric patients.[8]

Visual analytical techniques can be used to rapidly analyze relationships between variables by dynamically interacting with all of the variables within the database.[11–13] This approach has been used to evaluate business processes in order to gain new perspectives about big data sets.[14] In this article, we describe the application of the visual analytical approach to providing dynamic, individualized, surgical blood product clinical decision support.

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,[15] 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).[16] The CPT-4 codes were referenced with cross-walks developed by the ASA.[17]

Patient subcategories were created for each of the demographic variables. The user interface allows selection of any range for the age or weight variables. We created predefined age category filters to fit the distribution of the study. The groups were defined as younger than 1 month, 1–6 months, 6 months to 1 year, 1–3 years, 3–10 years, and older than 10 years. Weight was treated as a continuous variable. The case length was calculated from the AIMS database timestamps denoting the patient arrival and departure times in the operating room.

The blood product data included the following categories: packed red blood cells, fresh-frozen plasma, platelets, cryoprecipitate, fresh whole blood, and reconstituted blood. Reconstituted blood consists of a 1:1 mixture of packed red blood cells and fresh-frozen plasma.[18] In order to facilitate comparison of transfusions across various groups, we calculated the aggregated volume of blood products transfused divided by the patient's weight. The aggregate measurement consisted of the sum of volumes for packed red blood cells, reconstituted blood, and fresh whole blood. The resulting measure of volume/mass (mL/kg) of blood product transfused is used routinely in clinical practice.

The aforementioned databases were combined, cleansed, preprocessed, and reduced to a dimensional model using a visual analytical software tool (Qlikview; QlikTech, Radnor, Pennsylvania, USA).[19] A graphical user interface in Qlikview was designed to allow the exploration and identification of trends, patterns, correlations, and data distributions, and the detection of outliers of the study variables through the use of color, interactive navigation, and graphical zooming.

Each numerical variable was evaluated independently using frequency analysis histograms, which were generated for each numerical variable (y-axis, frequency; x-axis, variable). Bar charts were used to display categorical data and nominal, ordinal, and interval variables, while scatter plots were used to explore data relationships and types. Finally, we took advantage of the associative in-memory engine represented by graphical data filters to query the entire dataset, which allowed us to explore every variable and its association with every other data point anywhere in the entire schema in real time.

Descriptive statistics (mean, SD, median, minimum, maximum, percentage of total) of all blood product types were developed into the model for analysis of the selected procedures. Outlying values in the upper/lower 1% in each variable were systematically flagged for individual chart review to assess data accuracy.

RESULTS

We retrieved 231 073 surgical procedure records from the AIMS database; a total of 3478 different types of surgical procedures were performed during the study period. The records were cross-referenced to the BB database to retrieve all associated data about blood products prepared for each patient. The databases were linked with a composite key consisting of each patient's medical record number and service date. A total of 8156 procedures required blood transfusions as identified by the administration of any blood product component. Our patient population age ranged from 0 days to 67 years, although the majority of the patients were younger than 18 years of age. The age distribution of patients who received blood transfusions is categorized in table 1. The visual interface allowed evaluation of relationships between variables, such as transfusion events and ASA physical status. Figure 1 shows the ASA physical status profile and associated transfusion rates for our patient population. Other filters such as weight, age, and procedure code can

Table 1 Distribution of patients receiving blood transfusions in each age group

Age group	No of procedures	No of patients transfused	Percentage transfused	Volume required (mL/kg)	Transfusion*		No transfusion*	
					Weight (kg)	Length (min)	Weight (kg)	Length (min)
1 month or younger	6532	1556	23.8	36.23 (47.64)	2.98 (0.73)	159.55 (75.37)	3.31 (2.92)	75.25 (61.19)
1–6 months	12 291	1915	15.6	21.84 (25.60)	4.76 (1.54)	139.01 (81.44)	5.11 (2.15)	65.72 (55.40)
6 months to 1 year	15 769	842	5.3	30.39 (31.74)	7.42 (1.64)	175.7 (90.60)	8.62 (6.94)	45.67 (51.77)
1–3 years	46 506	985	2.1	22.2 (28.13)	11.4 (2.47)	181.39 (99.90)	11.96 (6.55)	31.92 (46.14)
3–10 years	86 785	1150	1.3	20.75 (27.56)	19.68 (8.31)	201.3 (134.00)	22.52 (9.09)	37.84 (48.00)
10 years or older	63 062	1706	2.7	12.92 (15.90)	53.58 (19.10)	271.06 (164.00)	57.33 (21.79)	65.5 (71.00)
All age groups	230 945	8154	3.5	23.5 (31.70)	17.8 (21.30)	188.30 (123.10)	27.8 (22.70)	46.9 (57.80)

Values are mean (SD).
*Patients were divided into two groups based on administration of any blood product (Transfusion) or no blood product administration during surgery (No transfusion). The patient weight and surgery length is shown for each subgroup.

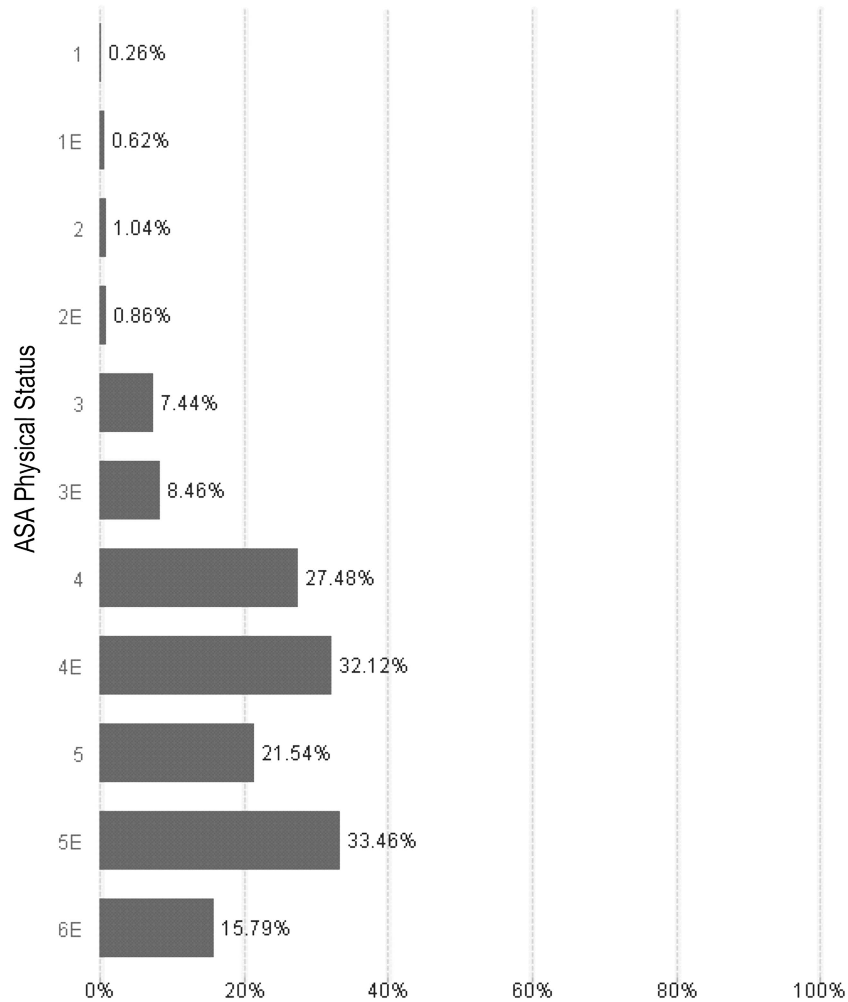

Figure 1 The American Society of Anesthesiologists (ASA) physical status categories describe patients as: (1) healthy (n1=63 315; n1E=4521); (2) mild systemic disease (n2=89 524; n2E=4430); (3) severe systemic disease (n3=56 459; n3E=3805); (4) severe systemic disease that is a constant threat to life (n4=6306; n4E=1943); (5) moribund, not expected to survive without surgery (n5=65; n5E=263); (6) declared brain dead, organ donor (n6=15; n6E=19)[15]. The 'E' modification indicates emergency surgery. We used the ASA physical status as a primary filter to identify patients who received blood transfusions within each ASA group. The incidence and proportion of patients receiving blood transfusions at each classification increases with severity of disease and emergency surgery.

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 products. 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.[7] 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

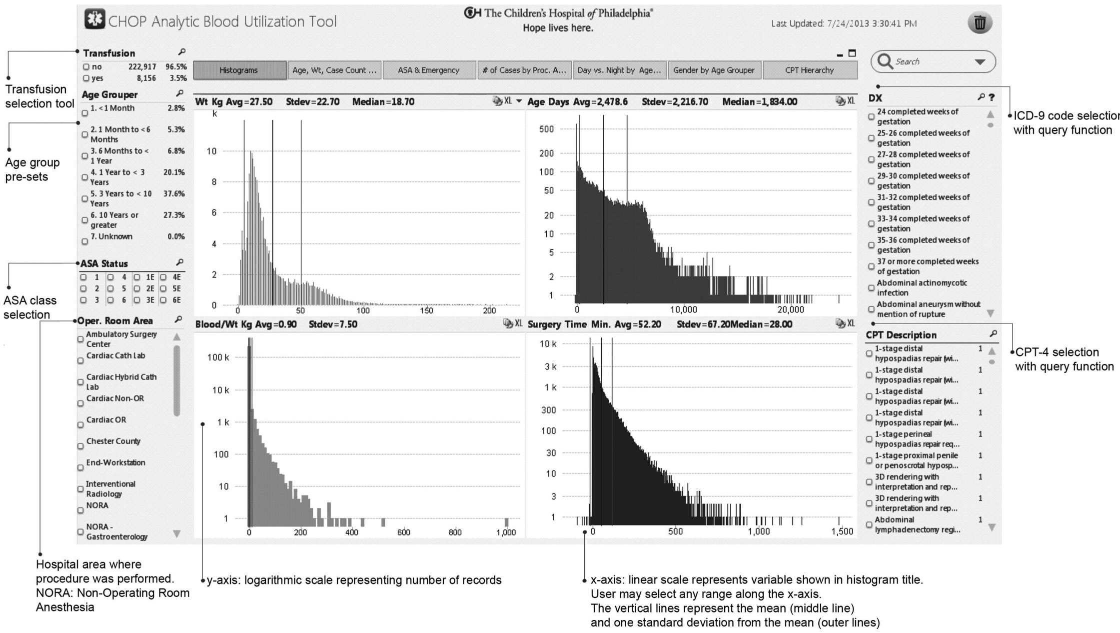

Figure 2 The user interface allows selection of any number of filters. The 'Transfusion' section denotes patients who received any blood product or patients who did not receive any blood products during surgery. The 'Age Grouper' allows selection of predefined age categories. The 'ASA Status' allows selection of any American Society of Anesthesiologists (ASA) classification. The 'Oper. Room Area' allows selection of procedures based on the location within the hospital. On the right side of the screen, the 'DX' code represents the International Classification of Disease (ICD)-9 codes and the 'CPT (Current Procedural Terminology) Description' allows selection of specific procedures. Both the DX and CPT sections allow free-text search. The histograms displayed represent data distribution of individual variables. The vertical lines represent the average (red) and 1SD (gray). The top left histogram represents weight, top right is age in days, bottom left is the total blood product volume transfused in mL divided by the patient's weight (mL/kg), and the bottom right represents the surgery time (in min). The histograms update automatically when filters are applied.

determined in volume per body mass (mL/kg). Keung *et al*[20] 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

Table 2 Top 15 procedure categories associated with blood product transfusion for patients ≤1 month of age

Procedure	Volume required (mL/kg)	Percentage of patients transfused	No of procedures with transfusion	Total number of procedures
Cardiac (cardiopulmonary bypass)	38.32	82	1011	1237
Intracranial (excluding shunts)	58.23	65	11	17
Fetal surgery	7.14	50	1	2
Neonatal emergency (<1 month; premature; <45 weeks post-conceptual age)	52.88	30	17	57
Necrotizing enterocolitis	38.36	29	5	17
Premature infant—non-emergency (<45 weeks post-conceptual age)	93.7	27	4	15
Cardiac catheterization	20.59	27	134	504
Cardiac (no cardiopulmonary bypass)	24.58	23	181	802
Neonatal bowel obstruction	14.63	20	3	15
Intrathoracic/non-cardiac (intracavitary)	20.73	16	24	152
CT scan*	65.43	14	3	21
Craniofacial	20	14	1	7
Thoracic (superficial)	14.29	14	1	7
Gastroschisis	14.33	12	5	41
Plastic/reconstructive	18	12	2	17

The list is ranked by the percentage of each procedure group associated with blood product transfusions. The source of the procedure category is data entry at the AIMS user interface. This display allowed us to identify data entry errors, such as cardiac procedures with cardiopulmonary bypass, that are not associated with blood transfusions. Chart review revealed that these procedures were mislabeled as cardiopulmonary bypass procedures.
*Further examination revealed CT scans associated with blood transfusions. These charts were flagged for review and noted that CT scan consisted of one of the procedures performed during the anesthetic.
AIMS, anesthesia information management system.

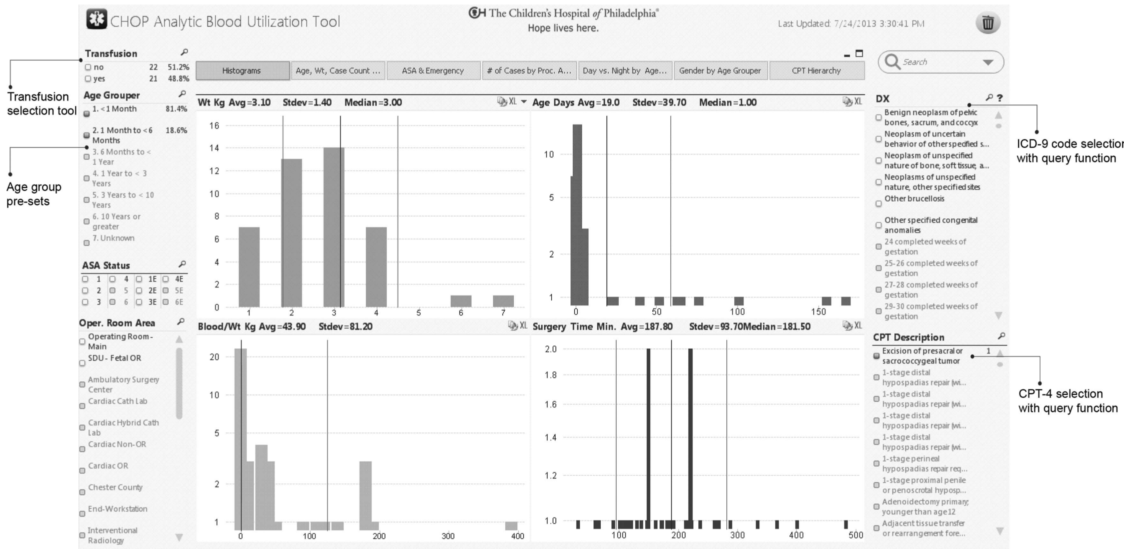

Figure 3 A real use case based on a clinical inquiry for transfusion requirements for neonates and infants younger than 6 months undergoing resection of a sacrococcygeal teratoma. This condition is usually present at birth and typically requires large transfusion volumes. The initial Current Procedural Terminology (CPT) filter retrieved 43 patients (age 0 days to 6 months), of which 21 received blood transfusions. The mean (SD) weight for the patients in this selection was 3.1 (1.4) kg, age was 19 (39.7) days, and transfusion requirement was 43.9 (81.20) mL/kg. For reference, the circulating blood volume in a term newborn is ∼90 mL/kg. ICD, International Classification of Disease.

data as well as data collected in the process of providing clinical care.

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 preprocedure 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.[8 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.

Contributors The following contributed to conception and design, acquisition of data or analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, and final approval of the version to be published: JAG, LA, AFS, EEL, CPB, DC, WRE, DF, DAS-P, MAR. AFJ contributed to conception and design, analysis and interpretation of data and revising the article for important intellectual content. JAG is guarantor for the integrity of the work, from inception to published article.

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Competing interests None.

Ethics approval Institutional Review Board at the Children's Hospital of Philadelphia.

Provenance and peer review Not commissioned; externally peer reviewed.

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.

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