Transfusion-related cost comparison of trauma patients receiving whole blood versus component therapy

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INTRODUCTION: With the emergence of whole blood (WB) in trauma resuscitation, cost-related comparisons are of significant importance to providers, blood banks, and hospital systems throughout the country. The objective of this study was to determine if there is a transfusion-related cost difference between trauma patients who received low titer O+ whole blood (LTO+WB) and component therapy (CT).

METHODS: A retrospective review of adult and pediatric trauma patients who received either LTO+WB or CT from time of injury to within 4 hours of arrival was performed. Annual mean cost per unit of blood product was obtained from the regional blood bank supplier. Pediatric and adult patients were analyzed separately and were compared on a cost per patient (cost/patient) and cost per patient per milliliter (cost/patient/mL) basis. Subgroup analysis was performed on severely injured adult patients (Injury Severity Score, >15) and patients who underwent massive transfusion.

RESULTS: Prehospital LTO+WB transfusion began at this institution in January 2018. After the initiation of the WB transfusion, the mean annual cost decreased 17.3% for all blood products, and the average net difference in cost related to component blood products and LTO+WB was more than $927,000. In adults, LTO+WB was associated with a significantly lower cost/patient and cost/patient/mL compared with CT at 4 hours ($p < 0.001$), at 24 hours ($p < 0.001$), and overall ($p < 0.001$). In the severely injured subgroup (Injury Severity Score, >15), WB was associated with a lower cost/patient and cost/patient/mL at 4 hours ($p < 0.001$), 24 hours ($p < 0.001$), and overall ($p < 0.001$), with no difference in the prehospital setting. Similar findings were true in patients meeting massive transfusion criteria, although differences in injury severity may account for this finding.

CONCLUSION: With increased use of LTO+WB for resuscitation, cost comparison is of significant importance to all stakeholders. Low titer O+ WB was associated with reduced cost in severely injured patients. Ongoing analyses may improve resource utilization and benefit overall healthcare cost. (*J Trauma Acute Care Surg.* 2023;95: 62–68. Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level IV.

KEY WORDS: Whole blood; cost; transfusion; trauma systems.

Since the first documented blood transfusion in 1795,[1] blood transfusion standards have significantly progressed including the ability to separate whole blood (WB) into its components (i.e., packed red blood cells [PRBCs], fresh frozen plasma [FFP], and platelets [PLTs]) for more specialized transfusion requirements. Challenges remain regarding widespread adoption of the use of WB. Specific concerns pertaining to the cold storage of WB raise concerns about changes to the coagulation profiles and logistics of shorter half-lives relative to component products. In contrast, the processing and logistics of WB storage may be simpler compared with component blood products, although no studies have been published to the authors' knowledge specifically analyzing blood banking logistics of component blood products and WB for transfusion in traumatically injured patients.

At this institution, blood products on board regional emergency transport vehicles use a system of cyclin to minimize waste and maximize usage, where older units are recycled back to the regional Level I trauma center. Whole blood units are stored in thermal isolation coolers, which are routinely inspected for consistency and temperature maintenance. Blood is "cycled off" prehospital transport after 14 days from helicopter transport units where it is transferred to ground emergency transport units. If not used within 28 days, it is cycled back to the regional Level I trauma center for immediate use. If these units reach 35 days, they are subsequently returned to the regional blood distribution center and removed from the donor pool.

Because a unit of donated blood is separated into components, multiple processing steps are needed to prepare the products for storage and transfusion to patients, each adding additional costs along the way. Literature supporting a balanced resuscitation (1:1:1 ratio of PRBC to FFP to PLT) has led to the increased use of WB for resuscitation of patients in hemorrhagic shock, and there is literature showing the difficulties encountered in maintaining balanced resuscitation, especially in massive transfusion (MT) scenarios.[2,3] Since 2017, multiple studies have

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demonstrated the benefit of using WB as a resuscitation strategy for hemorrhagic shock.[4–8] However, few studies have evaluated the costs associated with WB transfusion.[9,10] We hypothesize that WB transfusion is associated with reduced transfusion-related costs compared with component therapy (CT).

PATIENTS AND METHODS

A retrospective review was conducted of a prospectively collected institutional database of all trauma patients from a Level I trauma center with a catchment area that includes patients from rural, suburban, and urban locations. Subjects were compared from January 1, 2016, to December 31, 2021, and received either low titer O+ whole blood (LTO+WB), CT, or a combination of these products from time of injury (including before arrival) to within 4 hours of arrival. The cohorts analyzed were compared based on primary resuscitation fluid (i.e., CT or LTO+WB). If patients received both blood components and LTO+WB, then they were grouped based on larger volume received from time of injury to 4 hours after arrival. Patients who did not receive blood in prehospital setting or within 4 hours of arrival were excluded from this analysis. All transferred patients, patients with missing blood transfusion records, and vulnerable populations were excluded (e.g., confirmed pregnancy, incarcerated). A CONSORT diagram of patients included in the analysis can be found in Figure 1, and data regarding injury characteristics, number of subjects, and blood product group of those patients who were excluded are referenced in Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C940.

At this institution, CT resuscitation occurred throughout the study inclusion period, while LTO+WB transfusion started in January 2018. Institutional review board approval from the participating institution was obtained before initiation of this study. The manuscript has been prepared in accordance with the Equator Network STrengthening the Reporting of OBservational studies in Epidemiology guidelines (www.equator-network.org), and a checklist can be found in Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C939. Cost data were obtained from the regional blood distribution center that services the participating institution in this study and the surrounding region. Institutional annual charges for each blood product and per unit pricing are available in Supplemental Digital Content, Supplementary Table 2, http://links.lww.com/TA/C941. These charges reflect the institutional charges for the blood products averaged on a yearly basis for each individual blood component or WB. All costs were tabulated in US dollars. Institutional costs of storage, processing, and maintenance were not included in this analysis.

Determination of which blood product received was based on the available blood product on prehospital emergency transport vehicles or in the emergency department at the time of the event. Before 2018, all prehospital transfusion was with component blood products. Prehospital transfusion of LTO+WB began in January 2018, with progressive expansion into neighboring counties in the institutional catchment area. Transfusion of products was based on regional transfusion guidelines and provider discretion (Supplemental Digital Content, Supplementary Table 3, http://links.lww.com/TA/C942). Pediatric (younger than 18 years) and adult patients were analyzed separately and were compared on a cost per patient (cost/patient) and cost per patient per milliliter (cost/patient/mL) basis. Subgroup analysis was performed on the adult population to assess for differences in the severely injured patients (i.e., Injury Severity Score [ISS], >15) and patients who underwent MT.

Data pertaining to demographic information, injury characteristics, prehospital transfusion records, hemodynamic parameters,

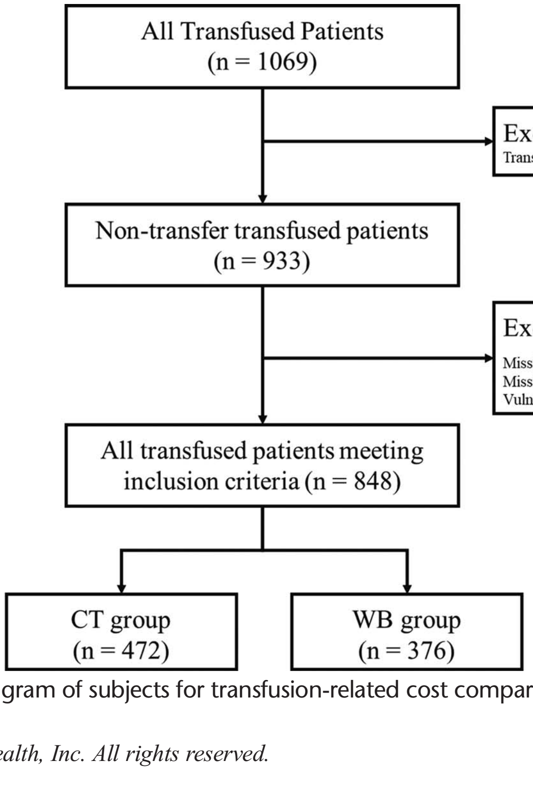

Figure 1. CONSORT diagram of subjects for transfusion-related cost comparison.

blood component volumes, and in-hospital outcomes were collected from an internally maintained trauma registry. Patient and blood bank records were reviewed and queried for relevant clinical information not available in the institutional trauma registry (e.g., time and date of transfusion, in-hospital blood transfusion volumes). Patients were deidentified, and specified data points were tabulated in a REDCap online electronic database (Vanderbilt University, Nashville, TN).

The primary outcomes for this study were total length of stay transfusion-related costs, 24-hour transfusion-related costs, and 4-hour transfusion-related costs. Secondary outcome for this study was prehospital transfusion-related cost. Operational costs related to storage, processing, and testing of blood products were not assessed in this analysis. Total hospital spending on each blood product per year was also analyzed for reference and comparative analysis. Because of the retrospective nature, a power analysis was not conducted. Descriptive analyses were performed using Mann-Whitney *U* test for continuous variables and Pearson's χ^2 analysis for categorical variables. All statistical comparisons were performed using IBM SPSS Statistics for Windows, version 28.0 (IBM Corp., Armonk, NY; 2021).

RESULTS

Over the entire study period, there was no significant difference in the cost per year for any of the component blood products or LTO+WB. Before the initiation of the WB program at this institution, the annual average cost spent on all blood products was $5,351,445.09. After initiation of WB transfusion for traumatically injured patients in January 2018, the average annual cost was decreased by 17.3% to $4,423,723.52. This was a net annual reduction of more than $927,000. In addition, the average annual cost of each blood product decreased after the initiation of WB as well (Fig. 2). The largest percent reduction in price was for PLT and FFP at 33.1% and 51.9% with an annual average net reduction of more than $563,000 and $160,000, respectively. The cost of PRBC was reduced by 25.2% with an annual average net reduction of more than $729,000 after the initiation of the WB program. Program costs incurred for cryoprecipitate had the lowest percent reduction at 19.3% with an average net reduction of more than $85,000 annually. Notably, the average total annual reduction was $1,539,151.83, which is $927,712.58 more than the average increase in spending due to the use of LTO+WB per year at $611,439.25 (see Supplemental Digital Content, Supplementary Table 4, http://links.lww.com/TA/C943, for full tabulation of average annual cost data).

There was no significant difference between the CT and WB groups regarding age, race, body mass index, rate of penetrating injury or Trauma Injury Severity Score. There was a significantly higher proportion of males (63.1% vs. 72.9%, $p = 0.003$) in the WB group and a higher ISS (23.14 vs. 19.53, $p = 0.007$) in the CT group (Table 1). In the CT group, approximation of balanced component therapy (BCT) transfusion was assessed. Approximation of BCT was defined as a ratio approaching 1.0 to 1.0 ± 0.1 to 1.0 ± 0.1 of pRBC, FFP, and PLT, respectively. At 4 hours, approximate BCT was achieved in 153 subjects (32.4%). At 24 hours, approximate BCT was achieved in 147 (30.1%) of subjects.

In adults, LTO+WB was associated with a significantly lower mean cost/patient compared with CT at 4 hours ($740.24 vs. $1,102.97, $p < 0.001$), at 24 hours ($1,129.59 vs. $3,758.24, $p < 0.001$), and overall ($1,313.16 vs. $3,867.78, $p < 0.001$; Fig. 3). When analyzed on a cost/patient/mL basis, LTO+WB was similarly associated with a lower cost at 4 hours ($1.53 vs. $3.14, $p < 0.001$), at 24 hours ($2.64 vs. $12.00, $p < 0.001$), and overall ($3.02 vs. $12.29, $p < 0.001$; Fig. 3). Mean prehospital costs were significantly higher in the LTO+WB group ($183.57 vs. $109.54, $p < 0.001$), although this is not unexpected, as before the initiation of the prehospital WB program, emergency medical service agencies only carried PRBC for prehospital transfusion, and not all prehospital providers had this capability.

When looking at mean cost/patient and cost/patient/mL, similar findings were true in the pediatric cohort in the prehospital setting, at 4 hour, 24 hours, and overall (all $p < 0.001$).

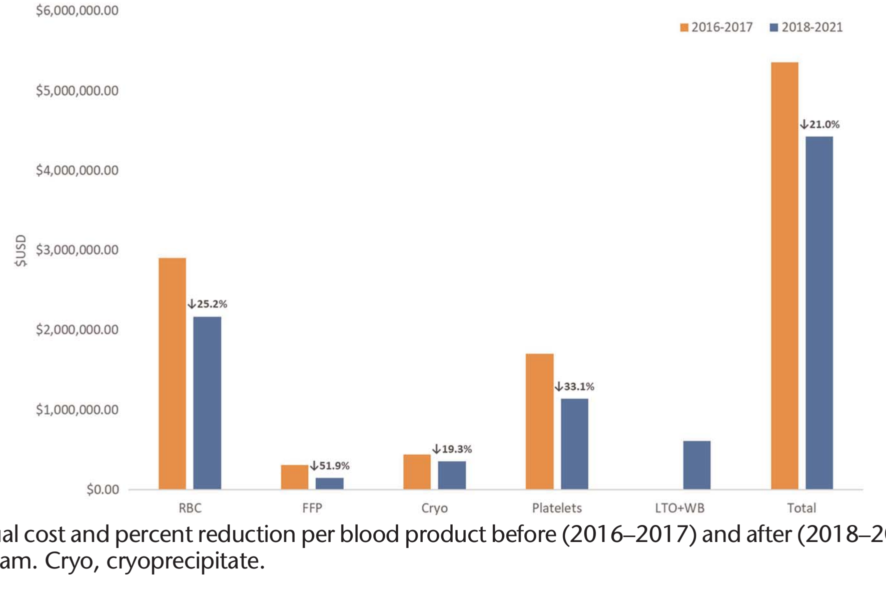

Figure 2. Average annual cost and percent reduction per blood product before (2016–2017) and after (2018–2021) initiation of whole blood transfusion program. Cryo, cryoprecipitate.

TABLE 1. Demographics and Injury Characteristics

	CT* (n = 472)	LTO+WB* (n = 376)	p**
Age	31.6 (23.0)	29.0 (21.6)	0.147
Male sex	298 (63.1%)	274 (72.9%)	0.003
BMI	26.7 (14.4)	29.3 (16.4)	0.146
White race	419 (88.8%)	327 (87.0%)	0.148
Blunt MOI	330 (69.9)	246 (65.4)	0.183
SI elevated	210 (47.9%)	110 (31.5%)	<0.001
ISS	23.4 (15.4)	20.0 (14.5)	0.007
TRISS	0.65 (0.38)	0.69 (0.38)	0.252
AIS head	3.31 (1.54)	3.35 (1.48)	0.713
AIS chest	2.95 (1.13)	2.75 (1.09)	0.049
AIS abdomen	2.83 (1.30)	2.66 (1.32)	0.226

*Values expressed as mean (SD) or n (%).
**Significance of $p < 0.05$ used. Comparisons made using Wilcoxon rank-sum test and χ^2 analysis.
BMI, body mass index; MOI, mechanism of injury; SI, shock index (elevated SI defined as SI >1); TRISS, Trauma Injury Severity Score.

In addition, these comparisons do not account for the added costs and time of preparing additional products required for CT (e.g., multiple bags compared with one WB unit), nursing time and resources, storage costs, and other potential unrecognized costs.

Subgroup analysis was then performed comparing only the most severely injured adult patients. In the severely injured subgroup (n = 312), there was no observed difference in ISS (30.0 vs. 31.1, $p = 0.490$) between the groups. In addition, there was no difference in the severely injured subgroup between Abbreviated Injury Scale (AIS) head (3.61 vs. 3.84, $p = 0.222$), AIS chest (3.14 vs. 2.99, $p = 0.203$), and AIS abdomen (3.12 vs. 3.04, $p = 0.626$) for CT and LTO+WB groups, respectively. Other demographic factors, such as age, body mass index, sex, and race were not significantly different. Low titer O+ whole blood was associated with a lower mean cost/patient at 4 hours ($950.08 vs. $1,267.41, $p < 0.001$), at 24 hours ($1,444.39 vs. $4,353.15, $p < 0.001$), and overall ($1,632.32 vs. $4,492.10, $p < 0.001$). When the severely injured cohort was compared on a cost/patient/mL basis, LTO+WB was associated with significantly lower cost at 4 hours ($1.93 vs. $3.62, $p < 0.001$), at 24 hours ($3.37 vs. $13.70, $p < 0.001$), and overall ($3.76 vs. $14.07, $p < 0.001$). There was no difference in average prehospital costs between the groups when compared on a cost/patient ($132.57 vs. $124.56, $p = 0.276$) or cost/patient/mL ($0.27 vs. $0.34, $p = 0.945$) basis (Fig. 4).

In the massive transfusion protocol (MTP) subgroup (n = 144), subjects were well matched in terms of demographics and mechanism of injury. There was no significant difference in ISS (27.2 vs. 23.9, $p = 0.559$), AIS chest (3.06 vs. 2.83,

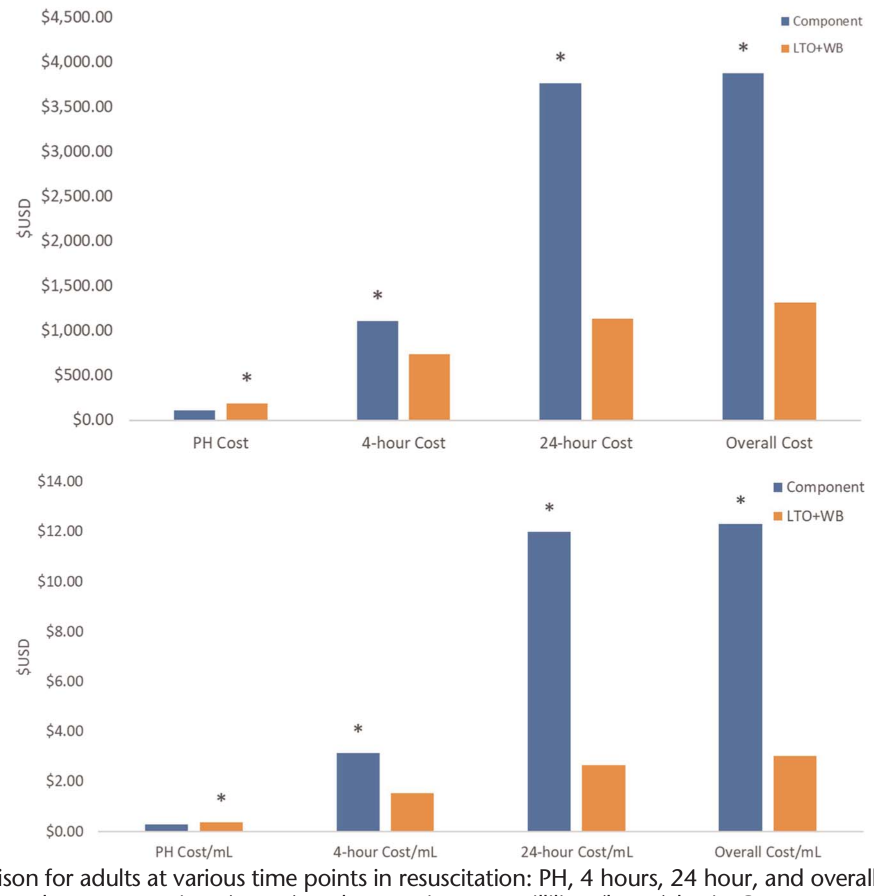

Figure 3. Cost comparison for adults at various time points in resuscitation: PH, 4 hours, 24 hour, and overall cost for adult patients. Cost comparison performed on a per patient (upper) and per patient per milliliter (lower) basis. Costs measured in $USD. *Indicates statistically significant difference. $USD, US dollars; PH, prehospital.

$p = 0.589$), or AIS abdomen (3.04 vs. 3.22, $p = 0.663$). The WB group of the MTP subgroup had a significantly higher AIS head compared with the CT cohort (3.23 vs. 5.00, $p = 0.011$). In comparison with CT, the LTO+WB group was associated with a significantly lower percentage of patients who required MT (5.1% vs. 37.7%, $p < 0.001$). This suggests that, in the MTP cohort, there may have been a difference in the injury patterns where the WB group appeared to have more patients with severe closed head injuries compared with the CT group, which may account for the difference in the percentage of patients requiring MTP.

The average cost of a theoretical MT using WB (i.e., 6 U LTO+WB) over the study inclusion period was $2,473.50. Comparatively, for an equivalent theoretical MT in a patient receiving CT (i.e., 6 U PRBC, 6 U FFP, 1 apheresis "six-pack" of PLT), the cost on average would be $2,104.00. In patients who met the institutional MT criteria, LTO+WB was associated with a decreased cost/patient at 24 hours compared with CT ($4,458.68 vs. $7,780.66, $p = 0.002$) and overall ($4,882.32 vs. $7,892.42), $p = 0.006$), but no significant difference was observed at the 4-hour period ($1,675.20 vs. $1,989.22, $p = 0.416$). Mean prehospital cost/patient was significantly higher in the LTO+WB group versus the CT group ($423.64 vs. $114.76, $p = 0.034$), which may be accounted for by the aforementioned change in regional transfusion practices. Of note, these charges do not reflect the significant costs associated with activation of an MT, which involves activation of pharmacy, anesthesia, additional nursing, blood bank, and more institutional resources for initiation of MT.

DISCUSSION

In the last several years, the body of literature analyzing the various benefits of LTO+WB from a physiologic and clinical perspective has grown significantly. However, there is a paucity of literature addressing the financial impact of WB transfusion practices. With 848 patients reviewed from 2016 to 2022, this study represents the largest study to date analyzing the financial impact of a WB program at a Level I trauma center.

Although there has been a relative increase in year-to-year costs related to LTO+WB, this seemingly is reflective of its increased utilization in conjunction with the reduced usage of other blood component products. Since the initiation of the WB program at this institution in January 2018, there has been a decrease in costs across all blood products and an overall cost reduction associated with transfusion. Bush and colleagues[9] conducted cost analysis in 2021 in which they analyzed 280 patients and were only able to demonstrate a significant decrease in the amount of PRBC transfused in patients who received WB and an associated cost decrease, not a decrease in the total cost or cost specific to other blood components (e.g., FFP, PLT,

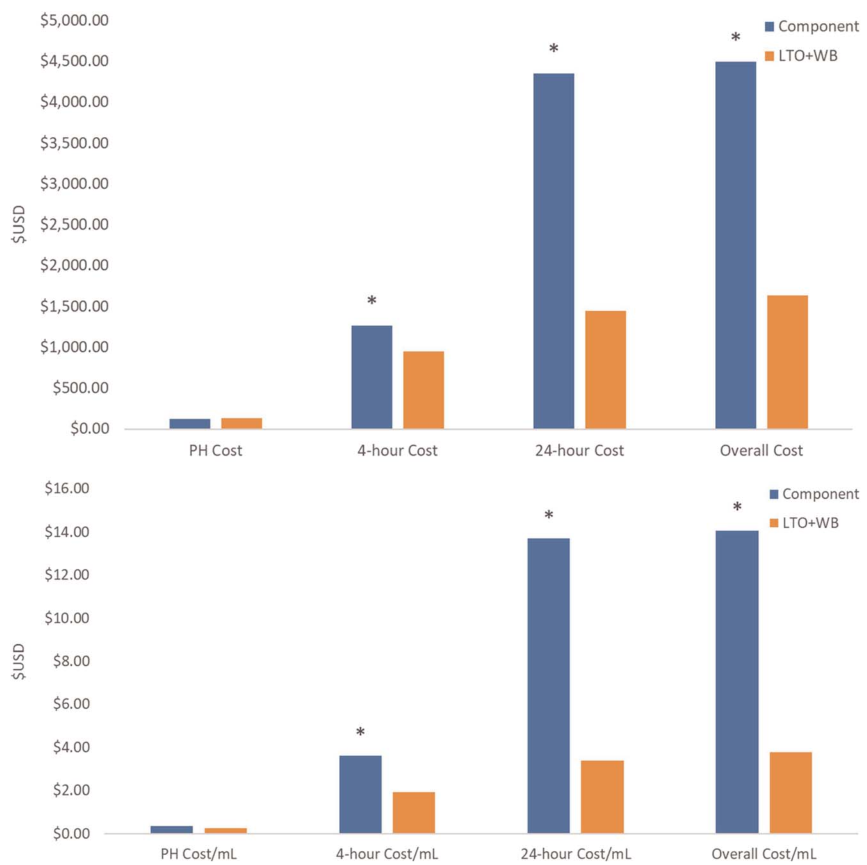

Figure 4. Cost comparison for severely injured (ISS, >15) adults at various time points in resuscitation: PH, 4 hours, 24 hour, and overall cost for adult patients. Cost comparison performed on a per patient (upper) and per patient per milliliter (lower) basis. Costs measured in $USD. *Indicates statistically significant difference. $USD, US dollars; PH, prehospital.

cryoprecipitate). Not only were we able to show a decrease in costs related to each component but we also demonstrated a net decrease in average annual spending of more than $927,000 when combining the increased mean cost per year from LTO+WB and the decrease in mean annual costs associated with CT. This suggests that WB transfusion in our patient population may also be reducing the amount of blood components transfused. Over time, the costs incurred related to the initiation of the WB program are expected to decrease as the practice becomes more established, thus possibly leading to further cost reductions.

The processing, storage, and transfusion costs related to WB and CT are challenging to quantify because institutional costs are typically not easily separated based on the department that uses them. Thus, some of the storage, processing, and laboratory costs related to maintaining WB and component blood products are incorporated into the institutional costs for blood products used throughout the hospital. Therefore, a direct determination of the differences may be lower for WB when compared with CT, but this cannot be determined without a complete audit of the entire institutional blood products processing and storage costs and was not able to be performed for this study because it contains many factors that cannot be accounted for.

Although there are no studies specifically comparing storage and processing factors between WB and balanced CT, one study from Stokes and colleagues[10] evaluating United Kingdom National Health Services data on transfusion-related costs estimated annual costs exceeded $175 million. Whole blood requires less physical storage space, does not need to be separated into components, and uses a simpler transfusion process (e.g., 1 U of blood product as opposed to three components). The shelf life of WB is considerably shorter than component blood products, and there are many clinical indications for which WB is not necessary. Therefore, the use of WB in trauma may be associated with increased efficiency of transfusion and decreased storage related costs, but this cannot be directly determined in this study. The generalizability to other medical indications for transfusion is likely not as robust and is beyond the scope of this manuscript. In the future, analyses of cost, efficiency, and profitability require a more in-depth analysis of institutional and regional blood banking practices and should be conducted.

Balanced resuscitation with components in a 1:1:1 ratio has been traditionally recommended to approximate WB losses. McCoy and colleagues,[11] however, summarized the composition of WB versus CT transfused in a 1:1:1 ratio and demonstrated that WB had a greater baseline hematocrit, PLT count, and higher concentration of coagulation factors, all while being able to be stored in smaller volume product. In addition, balanced resuscitation is more challenging to practically achieve and becomes even more difficult with the increasing severity of trauma, number of patients, and amount of blood products transfused. April and colleagues[2] demonstrated that only 39.8% of massively transfused patients received a fully balanced resuscitation and up to 22% of patients did not receive a balanced resuscitation with either FFP or PLT therapy. Similarly, our series demonstrated comparable ratios of balanced resuscitation, with 32.4% of subjects at 4 hours and 30.1% of subjects at 24 hours receiving blood products that approached a balanced resuscitation. Because of its potential for improved compliance and simplicity in resuscitation, along with improved baseline coagulation properties, WB has the potential to offer a superior resuscitation product that is further supported by its use in MT situations.

Another advantage to using WB in traumatic resuscitation is the reduction in donor exposure. In a theoretical MT using CT versus WB (i.e., 6 U WB vs. 6 U pRBC, 6 U FFP, and six-pack of pooled PLTs), there is the potential for exposure to up to 18 donors in the CT group versus up to 6 donors in the WB group. While modern blood banking practices have significantly reduced the incidence of blood-borne disease transmission and transfusion reactions from exposure to nontype appropriate blood products, transfusion of any blood product still carries a risk of infection and/or transfusion-related reaction. Decreased donor exposure represents an additional way in which WB may provide an advantage over CT in traumatic resuscitation beyond a cost benefit.

This study demonstrates that WB transfusion in traumatic resuscitation is associated with a decrease in cost at 4 hours, 24 hours, and overall transfusion-related costs when compared with CT. This held true for both the pediatric and adult cohorts, and the association remained significant when accounting for cost/patient/mL transfused. Before 2018, WB was not transfused in the prehospital setting. The increased utilization of WB in the prehospital setting is reflected in the abrupt elevation in costs after 2018 associated with prehospital WB. After 2018, a decrease in costs related to CT is seen for all components across all time intervals.

A higher ISS was observed in the CT group compared with the WB group, which is a potential limitation in this study and must be considered when analyzing the results of the overall cohort. To account for these differences in injury severity, the most critically injured patients were analyzed for comparison (i.e., ISS >15 and patients receiving MT). In the severely injured subgroup, there was no difference in ISS, AIS head, AIS chest, or AIS abdomen. In this subgroup analysis, WB recipients were shown to have a significantly lower transfusion-related cost compared with CT at all three in-hospital time points and no difference in prehospital transfusion-related costs. This finding somewhat mitigates the differences related to injury severity seen in the overall cohort and suggests that, in the most critically injured patients, lower transfusion-related costs are in favor of WB. Future prospective studies should compare groups that are matched based on injury severity to definitively determine if this transfusion-related cost difference remains significant.

Similar differences in transfusion-related costs were found in the MTP subgroup as well, although these findings must take into consideration the differences in injury severity patterns. The higher average AIS head score in the WB group suggests that a larger number of patients with closed head injuries in the WB group and possibly more patients with severe thoracoabdominal trauma in the CT group may have contributed to the cost differences observed in the MTP subgroup analysis.

The implementation of a prehospital WB program has the potential for the overuse of WB in the prehospital setting. Regional transfusion guidelines have been implemented[12] to direct prehospital providers on appropriateness of prehospital transfusion. However, guidelines were initially not instituted in the early stages of the regional WB program; thus, the occurrence of unnecessary transfusion may have occurred and is an inherent limitation to this study. To account for this, the standardization of prehospital transfusion guidelines for this region occurred during the study inclusion period and thus may be a small contributor to the outcomes of this study, but this cannot be definitively determined. Furthermore, current prehospital transfusion guidelines allow for clinical judgment to determine for patients who do not meet the strict transfusion guidelines but whom providers deem concerning for hemorrhagic shock. This flexibility could potentially lead to overtransfusion of prehospital WB and may account for the higher costs seen in the LTO+WB group in the prehospital setting. In addition, this may explain why the WB cohort had a lower ISS.

This study represents a single-institution retrospective review of the costs associated with early transfusion of WB versus CT in injured patients. Because this was as single-institution study, costs may differ in other regions, and our data may not be reflective of other parts of the country. In addition, the practices of transfusion in resuscitation of traumatically injured patients have evolved over the past decade with earlier blood product resuscitation and less reliance on crystalloid resuscitation fluids. Although this cannot be specifically accounted for in this study, these changes in practice patterns may have affected the outcomes with earlier resuscitation and less overall blood products. Future studies are needed to effectively determine this and compare transfusion related costs between groups that were transfused over the same period. Lastly, an inherent limitation to this study is the exclusion of subjects because of missing transfusion related data. It is noted that often subjects with missing transfusion data are typically those who have MT requirements; thus, this may have impacted the data related to transfusion-related cost. As referenced in Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C940, the demographics and injury characteristics of the subjects with missing or unconfirmed transfusion data were not significantly different between the 2 groups and accounted for only 37 subjects. This is a limitation of retrospective studies and must be considered when analyzing the results of this study. Future studies at this and other institutions should focus on maintaining complete transfusion records as to not introduce bias related to missing data.

The costs analyzed were limited to costs charged to the participating institution during the study period averaged over each year for each blood product and did not consider institutional costs of storage, processing, and maintenance. Inherent patient-specific costs and hospital costs were not included in the analysis. The cumulative effect of these costs is unknown and likely varies by region. Future prospective studies are warranted to further analyze transfusion-related costs and the relationship to overall hospital expenditures and operational costs.

In conclusion, the use of WB is expanding to include resuscitation related to traumatic injury and some nontraumatic indications (e.g., upper gastrointestinal bleed, obstetric hemorrhage), and therefore, analysis of the cost-related impacts is vital to hospital systems, providers, and various other stakeholders. This study represents the largest review of a transfusion-related cost comparison of WB and CT to date and demonstrates that the benefits of WB may extend beyond physiologic improvement and possibly reduce transfusion costs.

AUTHORSHIP

A.C., J.C.M., M.B., and D.J. contributed in the writing, data collection, literature search, and data analysis of the manuscript. A.C., J.C.M., M.B., J.B., R.S., B.E., S.N., and D.J. contributed in the critical revision and data collection of this study.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. "Highlights of Transfusion Medicine History". AABB.org. Available at: https://www.aabb.org/news-resources/resources/transfusion-medicine/highlights-of-transfusion-medicine-history. October 2, 2022.
2. April MD, Fisher AD, Hill R, Rizzo JA, Bynum J, Schauer SM, et al. Adherence to a balanced approach to massive transfusion in combat casualties. *Mil Med*. 2021.
3. Hynes AM, Geng Z, Schmulevich D, Cacchione PZ, Wade CE, Cannon JW, et al. Staying on target: maintaining a balanced resuscitation during damage-control resuscitation improves survival. *J Trauma Acute Care Surg*. 2021;91(5):841–848.
4. Mapp JG, Bank EA, Osborn LA, Stringfellow ML, Reininger DW, Winckler CJ. Epidemiological and accounting analysis of ground ambulance whole blood transfusion. *Prehosp Disaster Med* 2020;35(1):98–103.
5. Braverman MA, Smith AA, Pokorny D, Nicholson SE, Stewart RM, Jenkins DH, et al. Prehospital whole blood reduces early mortality in patients with hemorrhagic shock. *Transfusion*. 2021;61(Suppl 1):S15–S21.
6. Leeper CM, Yazer MH, Neal MD. Whole-blood resuscitation of injured patients' plasma. *JAMA Surg*. 2021;156(1):101–102.
7. Leeper CM, Yazer MH, Triulzi DJ, Neal MD, Gaines BA. Whole blood is superior to component transfusion for injured children: a propensity matched analysis. *Ann Surg*. 2020;272(4):590–594.
8. Bjerkvig CK, Strandenes G, Hervig T, Sunde GA, Apelseth TO. Prehospital whole blood transfusion programs in Norway. *Transfus Med Hemother*. 2021;48(6):324–331.
9. Bush K, Shea L, San Roman J, Pailloz E, Gaughan J, Porter J, et al. Whole blood in trauma resuscitation: what is the real cost? *J Surg Res*. 2022;275:155–160.
10. Stokes EA, Wordsworth S, Staves J, Mundy N, Skelly J, Stanworth SJ, et al. Accurate costs of blood transfusion: a microcosting of administering blood products in the United Kingdom National Health Service. *Transfusion*. 2018;58(4):846–853.
11. McCoy CC, Brenner M, Duchesne J, Roberts D, Ferrada P, Cotton BA, et al. Back to the future: whole blood resuscitation of the severely injured trauma patient. *Shock*. 2021;56(1S):9–15.
12. Pokorny DM, Braverman MA, Edmundson PM, Nicholson SE, Stewart RM, Jenkins DH, et al. The use of prehospital blood products in the resuscitation of trauma patients: a review of prehospital transfusion practices and a description of our regional whole blood program in San Antonio, TX. *VOXS*. 2019;14:332–342.