ISBT Science Series
An affiliated publication to Vox Sanguinis

ISBT Science Series (2019) **0**, 1–11

ORIGINAL PAPER

DOI: 10.1111/voxs.12498

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

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Background Prehospital management of the traumatically injured patient has evolved significantly since the organization of emergency medical services across the United States in the 1970s. Initially focusing on the utilization of crystalloid solutions to restore shed blood volume, robust military and civilian trauma experiences led to a modern day shift towards balanced blood component and ultimately whole blood use for immediate volume replacement. In addition, prehospital transfusion or remote damage control resuscitation (RDRC) has been widely adopted. This has led to point of injury resuscitation using blood products both in the United States and abroad.

Objectives This article will review the evolution of civilian and military prehospital resuscitation as well as the current practice of prehospital whole blood transfusion in the civilian trauma population in the United States. Additionally, we will provide an overview of our regional trauma system's use of whole blood with focus on the programme infrastructure, donor programme, product rotation schedule and logistical challenges. Finally, we provide three case report examples of the effective use of whole blood in our civilian emergency medical services (EMS) programs.

Key words: prehospital, resuscitation, trauma, whole blood.

Received: 23 April 2019,
revised 11 June 2019,
accepted 20 June 2019

Introduction

Prehospital management of the traumatically injured patient has evolved significantly since the organization of emergency medical services across the United States in the 1970s. Initially emphasizing crystalloid solutions to restore shed blood volume, robust military and civilian trauma experiences shifted the modern day focus towards blood and blood components for immediate volume replacement. In addition, prehospital transfusion or remote damage control resuscitation (RDRC) has been widely adopted. This article will review the evolution of prehospital resuscitation as well as the current practice of prehospital whole blood transfusion in the civilian trauma population in the United States. Additionally, we will provide an overview of our regional trauma system's use of

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whole blood. Finally, we provide three case report examples of the effective use of whole blood in our civilian emergency medical services (EMS) programmes.

History of civilian prehospital resuscitation in trauma

In the post-Vietnam War era, emphasis in the civilian sector was placed on the use of crystalloid in haemorrhagic shock. Shires *et al.* advocated the initiation of resuscitation in the prehospital setting in order to restore perfusion pressure; [1] an ‘asanguinous’ fluid bolus was given to the patient [2]. Supported mostly by animal studies and a computer model in which shed blood volume was replaced with balanced salt solutions, use of crystalloids continued into the 1990s [3,4]. In 1990, Kaweski and colleagues published a retrospective study examining the association between crystalloid administration and outcomes in 6855 trauma patients. While hypotension was clearly associated with an increased risk of death, volume of saline administered was not associated with a change in patient mortality [5].

Crystalloid administration was further challenged in 1992 by Kowalenko *et al* [6]. In a swine model of uncontrolled haemorrhage, the group showed that a ‘hypotensive resuscitation’ to a mean arterial pressure of 40 mm Hg as opposed to 80 mm Hg resulted in an 87·5% vs. 37·5% one-hour survival rate, respectively. Two years later, Bickell *et al.* reported improved outcomes in penetrating torso injury if crystalloid was delayed until operative control was complete. Patients who received balanced salt solution after control of haemorrhage and contamination had an 8% reduction in mortality and a significantly shorter hospital length of stay [7].

As prehospital transport times improved, trauma centres advocated for rapid transport over field intervention leading to some patients even arriving without IV access. This further reinforced the concept that restoring circulating volume did not necessarily affect patient outcome. Though this approach appeared to be ideal in short urban transports, it was not suitable for long distance or helicopter emergency medicine services (HEMS) transport. In 1997, the Mayo clinic, one of the first RDCR programmes in the world, published their experiences with haemorrhagic shock resuscitation during rotor-wing transport. Ninety-four patients were transfused packed red blood cells (PRBCs) in-flight between 1993 and 1996—the majority were trauma patients. Indications for transfusion included Hgb <10, persistent hypotension after a crystalloid volume challenge and/or clinical evidence of shock. Mortality among these patients was 52%, and no transfusion complications occurred [8].

In 2000, Sumida and colleagues reported their experience with in-flight transfusion of PRBCs vs. crystalloid. Forty-eight patients over a one-year period received either blood (n = 17) or crystalloid (n = 31). Despite being significantly more acidotic with significantly longer flight times (33·5 vs. 12·4 min), patients who received blood showed no mortality difference from crystalloid patients [9]. As experience with RDCR and prehospital blood product use expanded, the turn of the century would bring a shift away from prehospital crystalloid reliance.

Modern prehospital resuscitation

Prehospital resuscitation strategies remain variable across trauma systems in the United States. The Eastern Association for the Surgery of Trauma published a guideline on prehospital fluid administration [10], but there is currently no other widely accepted guideline based on level I evidence. Dadoo *et al.* published a survey of trauma protocols across several states evaluating trends in crystalloid administration [11]. Twenty-seven state EMS systems with publicly available protocols were reviewed—21 systems had end-points of resuscitation targeting systolic blood pressures when administering crystalloid. The recommended volume to be administered varied from 200 ml to 1 l depending on the system. However, the benefit of prehospital crystalloid administration remained unclear.

To address this question, Bores *et al.* [12] reported a retrospective study of patients captured by the Pennsylvania Trauma System Foundation’s Trauma Registry between 2008 and 2011. Of 2166 patients who sustained penetrating injuries, patients who received fluids had a higher Injury Severity Score (ISS = 18·68 vs. 16·36) and longer scene time (10·81 min vs. 9·18 min) but had similar Revised Trauma Score (RTS) and Trauma-Related Injury Severity Score (TRISS). The administration of prehospital crystalloid did not improve mortality (23·43% vs. 21·30%), but was associated with increased hospital, ICU and ventilator days. This result was echoed by Kikuta *et al.* [13] where they reported no mortality difference but increased ventilator days in patients receiving prehospital or in-hospital preoperative fluids.

Early work by The Mayo Clinic and Norwegian HEMS units demonstrated that prehospital blood transfusion in civilian systems was feasible. In 2014, Norwegian HEMS stocked O-negative PRBCs; they progressed to leucocyte-reduced cold-stored whole blood (WB) in 2015 [14]. Other countries also began carrying blood products. In 2012, London’s Air Ambulance switched from permissive hypotension with crystalloid to carrying PRBCs. In a retrospective study of that system, Rehn and colleagues evaluated outcomes of patients treated with either hypotensive crystalloid resuscitation or PRBCs. Of 539 patients with major haemorrhage, there was no difference in overall mortality between the two groups but there was a significant reduction in prehospital mortality in the PRBC group (27·6% vs. 42·2%) [15].

After starting a RDCR programme using PRBCs, the Mayo Clinic began primarily using thawed plasma in the mid-2000s [16]. In a retrospective review of 59 patients undergoing prehospital resuscitation, nine patients received early plasma transfusion followed by up to 4U of PRBCs. Fifty patients received a 'blood first' resuscitation. Despite a significantly different TRISS (0·24 vs. 0·66), degree of coagulopathy (INR 2·6 vs. 1·5) and lower systolic blood pressures (56 mm Hg vs. 76 mm Hg) in the plasma first group, there was no significant difference in early mortality (11% vs. 4% at 6 h). There was, however, a significantly higher 24-h mortality (44% vs. 10%) and overall mortality (56% vs. 18%) in the plasma first versus control groups, which is consistent with the predicted mortality based on the difference in TRISS scores [17].

Potential survival advantages conferred by plasma administration in the prehospital setting were further explored by the Prehospital Air Medical Plasma (PAMPer) group. In a multicentre, randomized superiority trial comparing incorporation of plasma resuscitation to standard care resuscitation, Sperry and colleagues reported a significant reduction in 30-day mortality in the plasma group (23·2% vs. 33·0%). When adjusted for crystalloid administration and prehospital blood transfusion in a multivariate regression analysis, plasma administration was associated with a 39% reduction in risk of thirty-day mortality [18]. The use of plasma by ground EMS agencies is difficult to investigate due to the logistical constraints of managing fresh frozen plasma (FFP).

In a randomized trial in Denver, Moore *et al.* examined the difference in survival when comparing prehospital FFP versus crystalloid during short ground transport. Between 2014 and 2017, 125 patients received plasma ($n = 65$) or saline ($n = 60$). Patients were similar in demographics including age and degree of injury and experienced similar transport times. There was no significant difference in 28-day mortality between the plasma versus saline groups (15% vs. 10%) [19]. Additional randomized controlled trials to investigate the impact of prehospital blood and plasma on survival in trauma patients are currently ongoing. Restricted crystalloid resuscitation along with early use of PRBCs, with or without plasma, appears to confer a survival benefit to patients. This is especially true in the case of long transport times where RDCR is necessary to prevent physiologic exhaustion and death from haemorrhage.

Recent discussion has focused on the potential benefit of prehospital platelets transfusion. Tissue injury resulting in haemorrhage activates the coagulation cascade leading to factor consumption. Crystalloid resuscitation dilutes the remaining coagulation factors worsening coagulopathy. As the process continues, enzyme reactions in the blood stream are altered leading to decreased platelet activation and fibrinolysis [20,21]. Concurrent with this, proteins that compose the endothelial glycocalyx are shed leading to decreased colloid osmotic pressure and increased vascular permeability [22]. As haemorrhage and hypoperfusion worsen, anaerobic production of lactic acid ensues perpetuating further loss of function of coagulation factors. Early administration of platelets has been suggested to rapidly restore the lining of the endothelial glycocalyx and stabilize proteins that were otherwise lost.

The storage and use of platelets and plasma provide logistical difficulties. Platelets must be used within 5 days of collection and expire rapidly after pooling. FFP, in its frozen state, may be stored for up to 3 years. Prior to use, it must be thawed in a warm bath for roughly 45 min necessitating ample notification. Once thawed, it must be used within hours to days depending on preservative and storage temperature.

Freeze-dried plasma (FDP), rather than FFP, was historically an option but was discontinued in the United States due to the risk of communicable disease transmission. FDP has been utilized by French medical teams for over 20 years with good success; however, their product was not cleared by the Food and Drug Administration (FDA) for widespread use during U.S. military operations. In 2012, U.S. Special Operations Command received an FDA waiver for limited use during combat operations in Iraq and Afghanistan [23]. While offering many of the clinical benefits of FFP, FDP avoids the logistical burden of cold-chain storage, is easy to carry and can be administered as soon as it is reconstituted. Currently, FDP is again undergoing FDA review for its use in the United States.

In an effort to provide the full benefits of FFP, platelets and PRBCs at the point of injury, WB is being re-explored for civilian prehospital resuscitation. WB has a longer life span (up to 35 days) than both FFP and platelets, contains less anticoagulant/preservative and is a physiologic solution. These facts alone make whole blood a much more viable option for point of injury resuscitation, especially where access to a trauma centre is not readily available (i.e. rural or remote areas). Unfortunately, the evidence to support whole blood over any other resuscitation product is currently lacking and often anecdotal. Studies are currently underway comparing its efficacy to other blood products in both the prehospital and in-hospital settings.

In 2017, EMS district 48 in Harris County, Texas, became the first civilian ground EMS system to carry and transfuse prehospital whole blood. Cypress Creek EMS, working with the same trauma centre as EMS 48, also deployed whole blood shortly after. In 2018, San Antonio Fire/EMS became the third ground EMS system to deploy whole blood; they simultaneously became the first major metropolitan city to fully incorporate WB into their regional trauma network.

Our system

In 2018, the University of Texas Health Science Center at San Antonio (UTHSCSA) and the Southwest Texas Regional Advisory Council (STRAC) partnered to implement the nation's first multidisciplinary, multi-institutional, regional low titre O-positive whole blood (LTO+WB) programme. Trauma Service Area P (TSA-P), the territory served by STRAC, encompasses 22 counties and roughly 26 000 square miles. This regionally managed programme engaged rural, urban and frontier prehospital and hospital settings with the goal of providing life-saving transfusion at the point of injury. The programme involved a four-stage approach: placement of LTO+WB on strategically dispersed HEMS units, placement within urban ground-based EMS agencies, establishment of a dense hospital network consisting of spoke and wheel-type placement around a pair of Level I trauma centres and the involvement of a regional blood centre to establish an adequate supply.

Product selection

As noted previously, research suggests that the effect of platelets on the endothelial glycocalyx may be invaluable in reversing traumatic haemorrhage. Unfortunately, platelet transfusion at the scene of injury is not currently feasible in our region for a multitude of reasons, including cost, rapid expiration and projected waste. As the majority of our facilities involved in the programme are not major trauma centres, the cost of continually purchasing a product that lasts only 5 days proved prohibitive. Plasma was also considered in our prehospital resuscitation pathway; however, we wanted to specifically administer a fluid that contained cold-stored platelets. Current FDA restrictions prevented the use of cold-stored platelets alone. However, because whole blood contains all the major blood components (including platelets) and can be easily stored/maintained for up to 35 days, it is a feasible method of achieving our regional resuscitation goals.

One concern regarding transfusion of un-crossmatched blood is the risk of isoimmunization of RhD negative (Rh-) pregnancy age females exposed to RhD positive (Rh+) blood. Literature quotes the risk of isoimmunization as 3%–6% of those transfused without administering Rh_o(D) immune globulin. The population of TSA-P is 63% Hispanic, 7% African American with the remainder mostly Asian and Caucasian. Although Asian and Caucasian populations have a slightly higher frequency of Rh- blood (15%–18%), African American and Hispanic populations are roughly 93% Rh+. Upon reviewing all trauma patients arriving to one of the city's Level I trauma centres in the 32 months preceding the LTO+WB programme, 715 patients (5%) received blood product transfusions; only 124 patients (0·9%) underwent activation of a massive transfusion protocol (MTP). Of the patients that underwent MTP, 20% were female. Only one female was Rh−. Half of the female MTP patients died of haemorrhage.

Extrapolation of the above data means that at our current MTP rate in TSA-P, it would take over 3000 months (250 years) to transfuse 100 Rh- pregnancy age females and only three to six of them would be at risk of isoimmunization. Over that same period, nearly 500 women requiring MTP upon arrival would have died from their traumatic injuries. With the risk of isoimmunization extremely low and the possible benefit of early blood-based transfusion high, we determined that the use of LTO+WB in our largely Rh+ region would be both safe and beneficial [24].

Donor selection

Initial donor selection relied heavily upon local demographics and the Army Blood Program/Joint Trauma System Clinical Practice Guidelines [25]. Partnering with the regional blood supplier, South Texas Blood and Tissue Center (STBTC), an initiative known as 'Brothers in Arms', was developed to identify male-only donors and obtain cold stored, low titre anti-A/anti-B agglutinin (< 1:256), non-irradiated, non-leucocyte-reduced whole blood [26]. To date, Brothers in Arms has screened 2600 volunteer donors of which 488 make routine donations; these 488 donors meet the requirements of the entire region. Over 1150 units have been drawn by collecting an average of six units per day, 7 days per week.

Equipment/Infrastructure

Military prehospital blood use led to rapid expansion of equipment and supplies needed to support the use of cold-stored blood outside of a hospital facility. To alleviate concerns about the reliability of cold storage in the extreme heat of South Texas, STBTC independently tested numerous refrigeration products. The Credo™ Cube with Thermal Isolation Chamber (Pelican Biothermal,™ Plymouth, MN, USA), modelled after the military's 'Golden Hour Box', was selected as a reliable, easy to use transport cooler. Coolers vary by size purchased and can carry anywhere from 2 to 56 units. We have two unit coolers onboard currently but STBTC has up to twenty unit coolers available for MCI events. The cooler's interchangeable 'insides' can be frozen and switched in seconds facilitates storage at a reliable temperature. These 'insides' can be frozen in any stand-alone, off-the-shelf, compact freezer. One 'inside' can maintain constant temperature up to 5 days per the manufacturer recommendation. Our assets currently replace the insides every 24 h as they rotate coolers among providers.

To continuously monitor the temperature of the product and confirm that it never rises above safe levels, iMini Multiuse Data Loggers (Cryopak, Edison, NJ, USA) were placed in each cooler in the field. Use of these data loggers confirmed that the LTO+WB remained within approved, safe ranges while outside the hospital setting. Temperature monitoring performed over the past year has shown an average temperature of around 3·7°C with no unit every going above the 10°C while in transit. Refrigeration of blood products at hospital facilities requires an FDA approved medical grade refrigerator. These refrigerators are not portable and require a dedicated, fixed location. This model of storage was used at helicopter bases but not on ground-based EMS units.

Rewarming prior to transfusion can be accomplished with any number of portable, commercially available devices. Our personal preference was the Warrior Portable Warmer System (QinFlow Inc, Plano, TX, USA). This system provided rapid warming (< 10 s from near frozen to 37°C) and quick administration (up to 200 ml/min). Utilization of this system required compatible blood tubing with a filter and a standard IV pressure bag.

Transfusion criteria

Life-threatening haemorrhage is the leading cause of preventable prehospital death; RDCR with blood products at the point of injury has shown great promise in reducing prehospital mortality [27–29]. One challenge with implementing prehospital LTO+WB was determining transfusion criteria. Busy EMS crews need quick, easily calculable criteria and strict decision pathways. Age, gender, mechanism of injury, vital signs, previous medical history and physical findings at the scene are all important considerations. To be considered for transfusion, we formulated a list of criteria based upon blunt or penetrating mechanisms (Table 1). In our region, we follow these criteria for any patient with evidence or concern for haemorrhage including women of child-bearing age and most paediatric patients.

A unit of whole blood contains a considerable volume of product (500–550 ml) and is too large for very young children. As a safety measure, it was decided that LTO+WB would be administered to any child over the age of 5 years old in our region since they would physiologically tolerate a bolus of the product. Any patient under the age of five would require consultation with medical direction (EMS physician) prior to administration.

A retrospective review of the highest tier trauma activations at our centre between 2013 and 2017 was conducted analysing patient shock index (SI) upon presentation to the emergency room and the prevalence of life-saving interventions (LSI). As SI (heart rate divided by systolic blood pressure) increased, the need for LSI also increased. However, the rate of LSI increased exponentially upon systolic blood pressure falling below 90 mm Hg. SI > 1 with SBP < 90 as a screening test was roughly 80% sensitive and specific for need for major intervention; because of its ease of calculation our EMS units have adopted SI as one of their first screening tools for prehospital transfusion—San Antonio EMS use IS of 1·2 specifically as part of their transfusion criteria (Table 2).

Upon arrival to the civilian trauma centre, patients who received prehospital LTO+WB were continued with that as their primary transfusion product. However, if they had not undergone prehospital transfusion, pregnancy age females (<55 years) and children were primarily given traditional component therapy in 1:1:1 ratio. Review of the first year of the programme suggested numerous benefits to LTO+WB use leading to practice changes at the civilian trauma centre. The facility will now transfuse any patient >10 years of age, regardless of sex, with LTO+WB. This will significantly increase our use in the hospital setting.

Emergency medical services involvement

After establishing a reliable donor pool and regional supply chain, the decision was made to initially carry products on HEMS units. Our regional HEMS units, capable of servicing a substantially larger area than ground-based units, provide ACLS transport and carry a critical care nurse onboard. In January of 2018, 18 helicopters covering all of TSA-P each began carrying two units of cold-stored LTO+WB. University Hospital (UH), the county Level I trauma centre, also began stocking LTO+WB for their trauma resuscitation unit (TRU). Brooke Army Medical Center (BAMC), the other Level I trauma centres, was already stocking LTO+WB as part of the Army Blood Program. As HEMS units transfused their product, they were able to replenish supplies either at the trauma centre or at STBTC.

The second phase of implementation involved the incorporation of ground-based EMS. Supplying every EMS unit with LTO+WB was a logistical impossibility that

Table 1 Transfusion criteria in San Antonio for hospital use of LTO+WB

Hospital transfusion criteria (Age > 5 years) **Penetrating trauma (Min 1 Parameter)**	**Blunt trauma (Min 2 Parameters)**
Physiologic parameters	
Systolic blood pressure (SBP) ≤ 90 mm Hg	
Heart rate (HR) > 120	
Shock Index (SI) > 1·2	
Pulse pressure (PP) < 45	
Positive focused assessment with sonography in trauma (FAST)	
Point-of-care lactate > 5 mg/dl	
Known anticoagulant use or dual antiplatelet therapy	
Signs of haemorrhage (high suspicion of internal bleeding or visual evidence of external bleeding)	

Table 2 Transfusion criteria in San Antonio for prehospital use of LTO+WB

Paramedic
For Patients in Hemorrhagic Shock:

Administer whole blood with signs of acute hemorrhagic shock as evidenced by:

- Systolic blood pressure < 70 mm Hg **OR**
- Systolic blood pressure < 90 mm Hg with Heart Rate ≥110 beats per min **OR**
- ETCO2 < 25 **OR**
- Witnessed cardiac arrest < 5 min prior to provider arrival and continuous CPR throughout
- downtime **OR**
- Age ≥ 65 years and SBP ≤ 100 AND HR ≥ 100 beats per minute

Relative contraindications

- Patient <6 years old
  - Consult Medical Direction if patient is in hemorrhagic shock and <6 years
  - Medical Director may elect to give blood in patients <6 years
- Religious objection to receiving whole blood—consult On Call Medical Director

would have led to unacceptable product waste. To determine areas of highest need, a zip code map plotting the location and frequency of regional trauma alerts requiring MTP upon arrival to the hospital was created (Fig. 1). This was further analysed to distinguish needs for both air and ground units. Medic Officers (MOFs), a group of ground-based EMS Lieutenants who serve as oversight for at least 10 EMS units in their sector of the city, perform constant patrols assisting with any difficult alerts. They are roaming subject matter experts that serve as experienced hands and guidance for patient care. MOFs are available 24 h per day, 7 days per week and drive a separate response vehicle with advanced life-saving capabilities. As there are only a few MOFs, they proved to be an excellent resource for the introduction of ground-based LTO+WB resuscitation.

The average ground transport time within our city limits is 30·8 min. EMS units rarely have time to administer significant resuscitative volumes after packaging and rendering initial aid. Each MOF carries one unit of cold-stored LTO+WB and a portable warming infuser. After notification of potential need for their assistance, the MOFs rendezvous with the on scene EMS unit and initiate transfusion if necessary. Transport time generally does not allow for administration of more than one unit of LTO+WB before hospital arrival. This is beneficial because it minimizes gaps in DCR; transfusion begins in the field and continues in transport, and the need is reassessed by the hospital care team.

An efficient system to restock from STBTC was established. After arriving at the hospital, MOFs are able to request resupply. STBTC immediately dispatches a courier to the hospital with replacement LTO+WB. Should the MOF have to leave early they also have the option of returning to STBTC's blood processing centre for full resupply. Either method allows for quick turnaround getting units back in service as soon as possible.

Rural involvement

As local assets grew more familiar with LTO+WB use and as logistical details proved successful, rural facilities requested to participate in the programme. Selection of higher volume centres surrounding both UH and BAMC in a hub and spoke model facilitated successful expansion across TSA-P. Two Level-IV facilities are currently carrying 1–2 units of LTO+WB, and 10 additional facilities have signed up to begin carrying the product. The addition of these facilities also provided the benefit of locations for potential resupply. Should HEMS units require

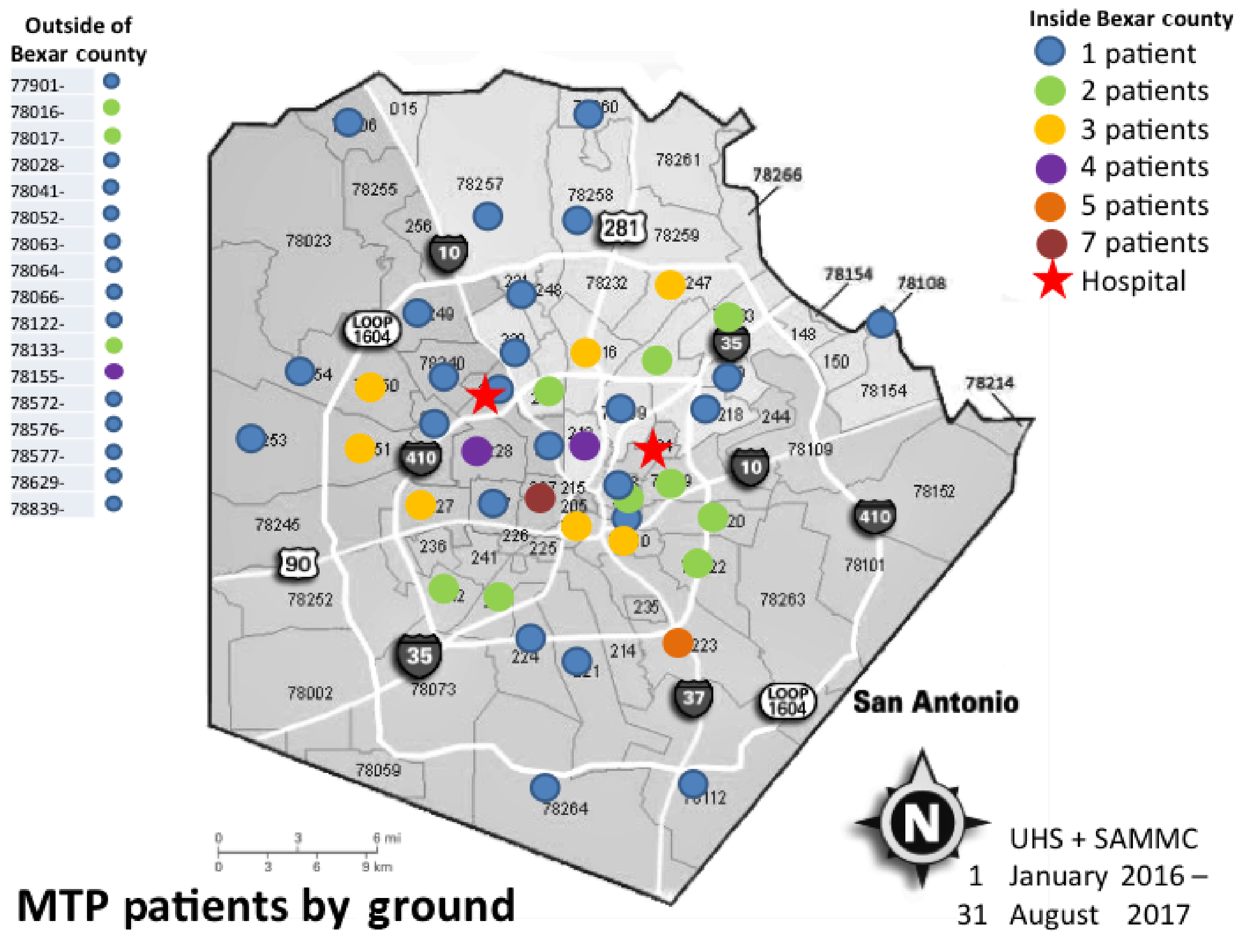

Fig. 1 Density map indicating areas distribution of patients requiring MTP upon arrival at the trauma centre.

immediate resupply prior to a transport or large volumes of blood for their patient they are able to borrow product from these outlying facilities. They may then replenish those sites upon their return trip.

Product rotation cycle

Our system provides roughly 50 units of LTO+WB for regional use at any given time. With the majority in transit onboard mobile units, a rotation schedule was created in order to minimize waste. STBTC uses CPDA-1 anticoagulant to provide each unit a 35-day life span. In our original rotation schedule, blood was first placed on HEMS units and remained there for up to 14 days. If not used in that time period, it was transitioned to ground units for an additional 14 days. At day 28, if still unused, it was taken to the Level I trauma centre where likelihood of use was high. However, because of redundant transitions leading to higher than expected waste, the rotation was simplified. Blood is now allocated to prehospital units and rural centres for the first 14 days and then shunted to the Level-I trauma centre for the remaining 21 days (Fig. 2).

Should the product not be used by day 35 it is returned to STBTC where a credit is applied towards the next units issued. Expired units are not broken into components but are used for training/field exercises to familiarize EMS and MOFs with their equipment. Initial waste was very low (2·5%). Extreme weather causing frequent grounding of HEMS units this past winter led to a spike in STBTC waste of up to 30% in November of 2018. However, by January 2019 the rates were again down-trending at 13%. After expanding our transfusion criteria at the trauma centre and adopting the new rotation system where blood enters the trauma centre after 14 days, we have dropped our regional product waste to roughly 2% with that number continuing to decrease (1·87% this last month). Thirty per cent of patients receiving emergency release whole blood at our trauma centre first received LTO+WB in the prehospital setting with the vast majority originating from ground units.

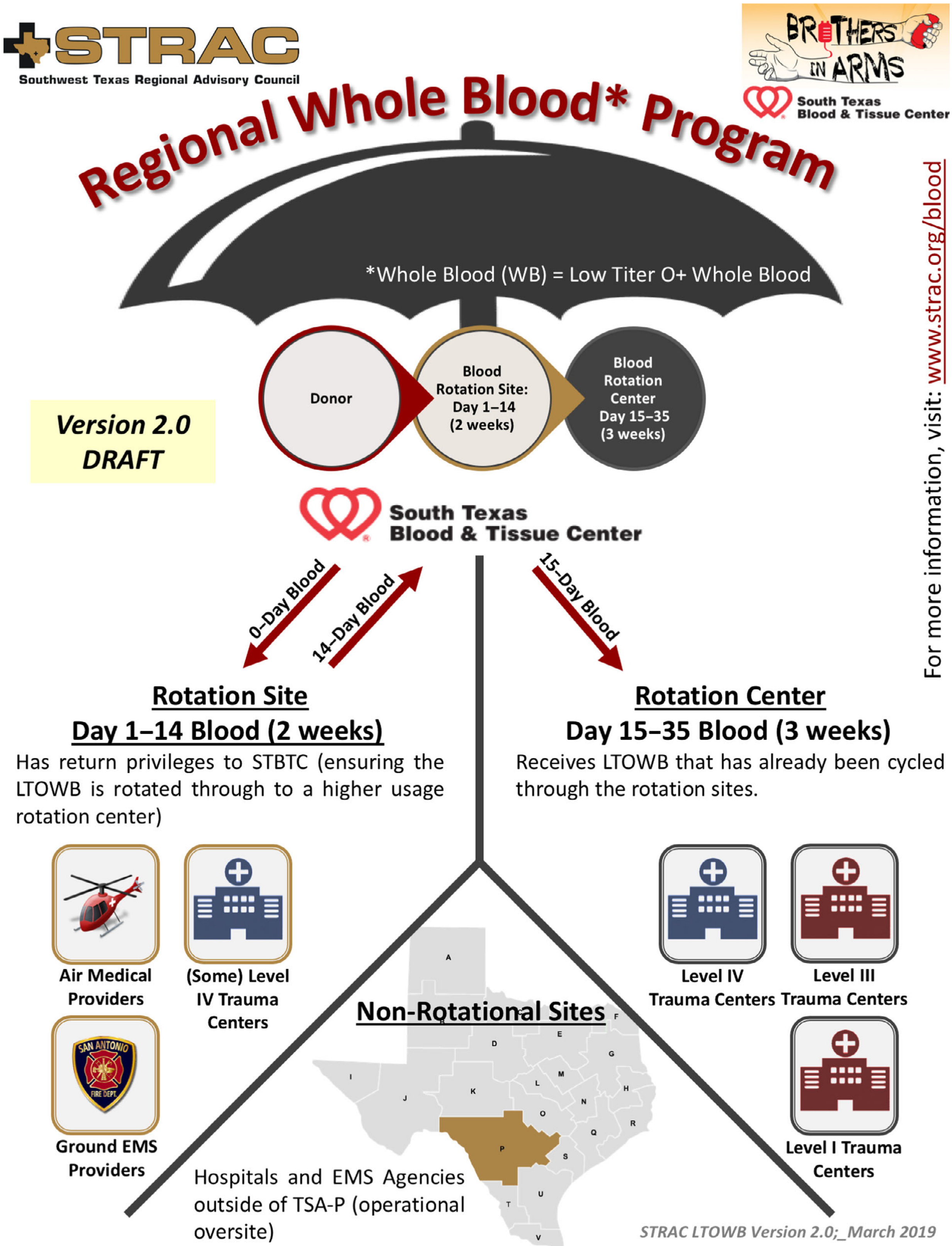

Fig. 2 Graphical depiction of the regional LTO+WB rotation cycle.

Key points

A multidisciplinary approach cannot be under-emphasized. A well-functioning programme required clinical, administrative, educational and promotional teams functioning in unison. Physicians, nurses, emergency medical technicians, paramedics, MOFs and police/sheriff special operators were trained in the utilization and administration of LTO+WB. STRAC and hospital administration provided the necessary support in lobbying to change current standards and practices. Public engagement was required to recruit donors for 'Brothers in Arms' and educate the region regarding new EMS capabilities. In addition, investment in necessary infrastructure such as coolers, temperature monitoring devices, blood tubing and portable fluid warmers facilitated the success of our programme. With the achievements of urban medical centres and their desire to fully co-operate within the region, growth into smaller more rural medical centres has been successful. Answers to frequently asked questions and more information regarding our trauma system's use of LTO+WB can be found at: https://strac.org/blood. [26].

Notable cases from TSA-P:

Functional recovery after blunt traumatic arrest

Patient #1, a 37-year-old woman, was involved in a single-vehicle rollover crash. EMS noted significant intrusion into the cabin and extensive damage to the steering column. The patient was initially alert and communicating appropriately. Upon extrication from the vehicle, the patient became unresponsive and lost pulses; she was intubated by EMS as cardiopulmonary resuscitation (CPR) was initiated. An intravenous catheter was placed, and the patient was given LTO+WB by a medical special operations medic with return of spontaneous circulation after approximately five minutes.

The patient remained hypotensive and unresponsive throughout HEMS transport receiving two additional units of LTO+WB. Immediately prior to arrival at the Level I trauma centre, the highest tier trauma alert was called. Upon arrival, her blood pressure was 94/70, pulse was 122, and she was ventilated at 20 breaths per minute, and her tidal volume was 500 ml. She was noted to have appropriate end-tidal CO_2 and bilateral breath sounds; her GCS was 3T. Her relative hypotension and blunt traumatic mechanism prompted continued use of blood-based resuscitation; in total, she received three units of LTO+WB, one additional unit of PRBCs and one additional unit of FFP. Radiographs of the chest and pelvis demonstrated no significant chest pathology. The pelvic ring was intact. Significant facial trauma and a large scalp laceration were also noted.

Fig. 3 Grade 5 splenic laceration with active extravasation.

The patient responded well with normalization of blood pressure and heart rate and was taken to radiology. Computed tomography (CT) revealed a grade V splenic laceration with active extravasation of contrast (Fig. 3). The interventional radiology team was activated, and the patient was taken to the hybrid angiography suite/OR where she underwent successful angioembolization of her spleen. She was taken to the ICU post-procedurally where sedation was lightened, and her neurologic status improved to 11T. The patient was extubated after a brief wean from the ventilator (<24 h). She was observed in the hospital for her other injuries which included cervical spine, rib and facial fractures. A subacute stroke, the aetiology of which was not clear, was later identified on follow-up imaging. The patient suffered no long-term sequela of this radiologic finding. At the time of discharge (<7 days), she was tolerating a diet, ambulating without assistance and was maintained in a cervical collar for her spine fractures. This patient is one of the first known examples where whole blood was provided to a pulseless, blunt injured motor vehicle crash patient, both at the scene of injury by ground crews and in air transport to the trauma centre.

Pinned in an oil field

Patient #2, a 23-year-old man, was working in a remote oil field approximately 100 miles south of San Antonio, Texas. While fixing a malfunctioning drill, the machine came down upon his right leg. He became entangled, and upon releasing the machine, he was noted to have a near-complete amputation of the right lower extremity. Co-workers immediately applied a belt around his right thigh and called 911. A Texas State Trooper, trained in first aid and the techniques offered in the American College of Surgeons Stop the Bleed Campaign [30], happened to be only 10 min away. Upon arrival, the trooper noticed that the makeshift tourniquet did not provide sufficient haemorrhage control. He applied a department-issued combat application tourniquet (CAT®—North American Rescue, LLC, Greer, SC) and was able to obtain adequate control until EMS arrived 10 min later.

The patient was noted to have significant blood loss due to the injury. His GCS was 13, and he was pale/diaphoretic. EMS quickly placed an additional tourniquet to the extremity, instituted spinal precautions, placed two 18 g peripheral IV's and bolused two litres of crystalloid. LTO+WB was not yet available to ground units that far from San Antonio. Intramuscular ketamine was given due to agitation, and the patient was placed on supplemental oxygen. Fentanyl was also administered on scene with momentary relief of the patient's pain.

The rural EMS agency immediately requested HEMS transport to a Level I trauma centre. The patient was persistently tachycardic to the 120 s but had a normal blood pressure. The patient's shock index was >1 but his SBP was also >90; due to this, he did not fully meet the dual criteria for prehospital transfusion in blunt injury. In the light of this, the flight team contacted EMS medical control requesting permission to administer tranexamic acid (TXA) and LTO+WB due to clinical concerns for haemorrhagic shock; medical control provided clearance. Upon arrival to the Level I trauma centre nearly 3 h later, the patient's blood pressure was still normal. He was still tachycardic to the 120 s but was no longer pale or diaphoretic. The patient required no further transfusion and ultimately underwent a right above knee amputation. He was discharged home with family 1 week later.

Big wells, Texas

In June of 2018, a caravan of three large sport utility vehicles packed full of people was spotted by US Customs and Border Patrol agents near the South Texas town of Big Wells. Border Patrol agents attempted to stop the convoy for inspection. The first SUV stopped, the second drove a short distance before also coming to a stop, and the third accelerated to a high rate of speed continuing down the highway. At a top speed of over 100mph, the vehicle lost control and crashed ejecting the majority of the 14 passengers.

At least nine EMS agencies (ground and HEMS) were dispatched to the area roughly 130 miles southwest of San Antonio. Unfortunately, 4 of the 14 passengers suffered catastrophic injuries and were declared dead at the scene. The remaining 10 patients were transported to the trauma centres via eight separate HEMS units. Six patients were taken to one of the Level I trauma centres and four to the other. One patient expired prior to arriving at a trauma centre.

Because LTO+WB is available on our regional HEMS units, three of the 10 transported patients met transfusion criteria and were given LTO+WB on scene and through the transfer process. One additional patient met criteria for transfusion but the crew did not have time to resupply their cooler before returning; he was given crystalloid en route. This incident is the first known recording of whole blood being used as the primary resuscitation agent on the scene of a civilian mass casualty incident.

Funding

Grant provided to the Southwest Texas Regional Advisory Council by The San Antonio Medical Foundation to purchase equipment supporting the programme.

Conflict of interests

The authors decalre no conflict of interests.

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