The role of our website will continue to be refined to provide rapid access to our resources and CME activities for our membership. International Trauma Care remains a not-for-profit organisation and all of these activities are supported by and produced by hard-working clinicians and support staff who do these activities in their own time and without financial reward. They all know why they do these things; it is because they care, for which they have my gratitude and admiration. I am honoured to have been the President of International Trauma Care (ITACCS) from 2002–2005 and I congratulate Jim Cain on his new role. I also look forward to our future collaborations and achievements.

BLOOD USE ISSUES

Blood Use in War and Disaster: The U.S. Experience

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Learning Objectives: 1) To review the history of blood use during wars and disasters in a large country with a well-developed blood service to provide examples for disaster planning, and 2) to review policy options for providing blood in emergencies.

Abstract

Several highly developed countries, such as the United States and Australia, first built national blood transfusion services during World War II. When the U.S. system was fully operational, the military ended up using only about 5% of the blood collected. Wars since that time, including Korea, Vietnam, and the first Gulf War, were smaller in scale and used an even smaller fraction of the total national blood supply, despite greater relative per-casualty blood use. The largest civil disasters are one to two orders of magnitude smaller then these medium-sized wars and generally last only 1 day. Thus, in the United States, there were four civil disasters between 1975 and 2000 where the care of the casualties required more than 100 units of RBC in the first 24 hours. In every case there was more than enough blood in local supplies and even more available in neighboring regions. Insuring an adequate blood supply for disaster and military needs requires only having an adequate national blood supply that can be tapped when disasters occur.

U.S. Army medical officers built the world's first blood bank at the Battle of Cambrai during World War I.[1] They oversaw the creation of a national blood program in World War II. In Korea and Vietnam, the wide availability of blood helped reduce the died-of-wounds rate from 12% of all casualties in World War I and the 6% experienced in World War II to less than 3%. The Korea and Vietnam in-hospital death rates are the lowest ever recorded for combat casualties, and approach the 2% in-hospital death rates of modern trauma centers. Since Vietnam, the numbers of casualties from our military actions have been small despite continuing planning for massive casualties using Cold War models.

This widening discrepancy between how we fight and how we plan causes several problems for the blood program. We spend scarce resources to build infrastructure that may not be of the right kind or in the right place. We train blood program officers to perform tasks that may never be required and fail to train them to see changing patterns of blood use as opportunities to improve casualty care. The public waste of blood threatens our relationship of trust with the donors that we will use their gift wisely.

To better understand changing patterns of blood use, it is useful to examine American military blood use and policy in the 20th century wars. Historic sources are available and living participants can be interviewed. A specific focus on the numbers of blood units provided, how the blood was handled, and what the participants thought they were accomplishing is useful. Blood use in civil and natural disasters provides a comparison. This article describes U.S. blood use in eight wars, five civil disasters, and three natural disasters.

Military Experience

World War I. The scientific basis for blood banking was discovered just before World War I. In 1913, Ottenberg and Kaliski[2] published a series of cases that showed that ABO typing largely prevented the "accidents and disasters" of transfusion. The following year, three separate individuals described the use of citrate as an anticoagulant. These discoveries were converted into the tools of modern blood banking, hemagglutination blood typing, and red blood cell storage solutions, by Peyton Rous and his colleague J. R. Turner[3] at the Rockefeller Institute in 1915 and 1916, and delivered to the battlefield by Rous' postdoctorial student, Lieutenant Oswald Robertson[4] of the Medical Officer Reserve Corps, U. S. Army, in 1917. Effective blood storage allowed the separation of donor and recipient in space and time.[5] Stored blood in bottles converted transfusion from an act of surgical bravado to an item of medical logistics and made it a professional service.[6] Blood transfusion became the accepted resuscitation therapy of the British Expeditionary Force to which American hospitals and physicians were attached in March 1918.[7]

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There is no record of how many transfusions were performed in World War I. Not all, or even most, American Expeditionary Force hospitals were transfusing blood at the end of the war. However, transfusion appears to have been used widely in those American hospitals with academic ties. Robertson's publications describe over 200 transfusions and, by the end of the war, he was running a school for blood transfusion that trained six teams a week. Harvey Cushing,[7] serving as a corps surgical consultant, noted that good hospitals in his sector were transfusing 50 units a day. From this kind of information one can estimate that altogether several tens of thousands of transfusions were performed in the spring, summer, and fall of 1918. This means that only a small proportion of all casualties received blood. In their massive review, *Medical History of the Great War*, the general staff and consultants of the Royal Army Medical Corps (RAMC) concluded that blood transfusion was the most important medical development of the war and clearly credit the invention to Robertson.[1] The equivalent American work makes no mention of blood transfusion.

World War II. Based on their World War I experience, the British entered World War II with a functioning blood transfusion system based on the Robertson model. The United States, entering the war 2 years later, decided that blood transfusion was too difficult and dangerous to promulgate on a worldwide basis, and that "blood substitutes," plasma and later albumin, were to be used as the primary treatment of hemorrhagic shock.[8] U.S. medical officers working in parallel with British hospitals in North Africa, India, and the South Pacific quickly realized that they lost patients with patterns of injury that British physicians were saving by using blood transfusion. *Blood Program in World War II* by Kendrick[8] is the best primary source on the U.S. military blood program and blood product development. This treatise describes the process by which each U.S. field army built a blood program in 1942 and 1943. By August 1944, the situation reached a crisis, as the large field armies in Europe and the Pacific needed more blood than could reasonably be supplied from their rear areas. Arrangements for the supply of whole blood by air from the United States were finally made at that time.

Figure 1 shows the number of units of whole blood sent from the United States to the European and Pacific Theaters in the last year of World War II. Approximately 500,000 units were sent in 13 months, reaching a maximum of 62,000 units in March 1945. This rate, 2,000 units a day, is the highest rate of blood shipment in U.S. military experience. At that time the United States had 12,000,000 men and women in its armed forces, about 9% of its total population. It had six field armies engaged on four major fronts, and it sustained approximately 30,000 casualties that month. Individual operations, such as the invasion of Okinawa, involved more men, ships, and planes than the entire U.S. military contains at the present time.

Three months earlier, in December 1944 and January 1945, the United States had fought in the largest land battle in its history, the Battle of the Bulge. There were over 81,000 American casualties and about 45,000 units of blood sent from the United States. Cold weather and slow evacuation presumably increased the mortality of injuries and reduced the usual demand for blood. At the same time, individual field hospitals and medical units in theater collected additional volumes of whole blood from the more than 2 million Americans present in France at the time. Despite the sense that "they were drawing blood all the way back to Paris," the contribution of the locally drawn blood to the total was

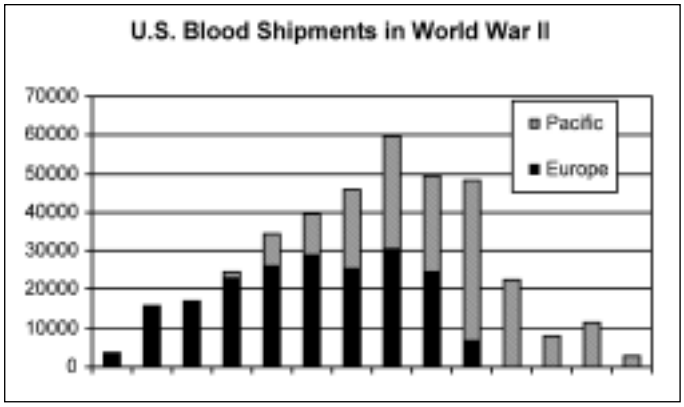

Figure 1. U.S. military blood shipments from the continental U.S. to the European and Pacific Theaters of Operation. The maximum, 2,000 units a day in March 1945, occurred as three American field armies crossed the Rhine in Europe and U.S. Forces fought in the Philippines and prepared for the invasion of Okinawa in the Pacific. (From Kendrick,[8] pages 559 and 630.)

probably small as locally available resources for drawing blood were modest. A large field hospital with an active transfusion program might have only a hundred reusable transfusion bottles and would be loath to part with more than a few.

More than 13 million pints of whole blood were drawn by the American Red Cross, under Army contract, during World War II for use and for production of freeze-dried plasma and albumin. The American Red Cross had been the U.S. Army's historic partner in World War I and had its own recent experience in Charles Drew's work collecting blood plasma for Britain. Some of the collected blood went for plasma product manufacturing with the red cells from 4 million units being discarded as waste, some units went to military hospitals in the Zone of the Interior, many units were diverted to civilian use, and a few, about 4%, went overseas. On a per capita basis, the 4 million units a year collected at that time were essentially equivalent to the 12 million units a year collected now, when corrected for a total population less than half as large, and with a much smaller fraction of older people, who use a disproportionately large fraction of the modern blood supply. Effectively, during World War II, the military built a national blood program and siphoned off a small portion for its own use. At the end of the war, military demobilization led to the collapse of the national blood program and its subsequent rebuilding as a fragmented civilian system.

Korea. Five years after the end of World War II, the United States entered the Korean War, without a military blood program. As a result, the U.S. military shipped no blood to Korea during the first 70 days of the war.[9] It was a time of chaos. Small military units were being fed into the retreating battle line piecemeal, and no medical units existed that were larger than brigade clearing stations. Such casualties as could be evacuated were loaded onto the floors of DC-3s and sorted on airstrips in Japan. The first blood from the United States arrived in Korea on September 6, along with the deployment of the first surgical hospital. The lack of a military blood program was a small part of a much larger lack of military preparedness. Assembling a military blood program, with military precedent and civilian examples and equipment, was easier than many other aspects of a hasty military medical response.

The total amount of blood used in the Korean War was about 400,000 units over 3 years. Over a 6-month period this never averaged more than 500 units a day (Fig. 2). Moreover, because of the 3-week storage life of ACD (acid citrate dextrose, the anticoagulant-nutrient solution used) whole blood, the long supply lines, and resultant short shelf-life of the units in country, probably less than half of all the available blood was used (Fig. 3). This blood wastage led the U.S. Army to invest in research on blood product development. Plastic blood bags were fielded almost immediately. Techniques for longer red blood cell (RBC) storage took another 30 years.

Vietnam. The war in Vietnam started slowly. In February 1965, the U.S. military was sending 10 units of whole blood every 10 days to a small Army surgical hospital in Saigon that supported an advisor group.[10] The attack on the U.S. advisor barracks at Pleiku that month caused more than 100 casualties. The immediate requirement for 123 units of blood was met by drawing fresh whole blood from other soldiers and civilians in the theater. The Vietnam War went on for the next decade, ultimately involving up to 525,000 U.S. military in country, as well as South Korean and Australian forces. In addition, the U.S. military provided some medical support to the indigenous Vietnamese. The blood program for that effort reached a maximum, in February 1969, of 36,000 units of RBC per month, about 1,200 units/day, available in country (Fig. 4). At that time, there were over 100 surgical teams in country.

The military blood program in the Vietnam War was fully operational for almost 10 years, and several useful lessons can be gleaned from it. Over the time period 1965–1971, about 1.3 million units of blood were sent to Vietnam and about 600,000 were administered in U.S. military hospitals. Thus, the in-theater wastage rate was about 54% or 100,000 units/year. This compares with a 15–35% wastage rate reported for civilian practice in the United States during the era of 3-week blood. Units near or at outdate were given to the Vietnamese. Military-sponsored clinical studies aimed at extending the storage period of whole blood to 4 weeks using CPD (citrate, phosphate, dextrose) and 5 weeks using CPDA-1 (citrate, phosphate, dextrose, adenine) continued during the war, but no licensed product resulted.

During 1965 and 1966, packed RBCs and fresh-frozen plasma became available. Small amounts of fresh whole blood were drawn in country for the production of platelets or for direct administration to coagulopathic casualties. The blood supply system could not guarantee the safety of this locally drawn blood, but the institutional memory, in the form of writings and teaching, of the surgeons who used it, attests to its safety and clinical usefulness.

Universal donor red cells were another widely used field expedient. More than 100,000 group–uncross-matched, universal donor transfusions were given without a single fatal hemolytic transfusion reaction reported. All nine of the reported fatal hemolytic transfusion reactions that occurred during the war followed the administration of misidentified cross-matched blood.[11]

Frozen RBC storage was used briefly in Vietnam. RBCs, frozen with the high glycerol method and stored at 80°C, were deglycerolized using the Huggin's cytoagglomerator and transfused within hours of preparation. Such a system was very resource-intensive. Four hundred sixty-five units of frozen RBCs were deglycerolized and used over 180 days, approximately 2.5 units a day, at a time when U.S. military usage in Vietnam averaged 600 units/day.[12] Thus, frozen RBCs were not an efficient or useful method of blood storage or utilization.

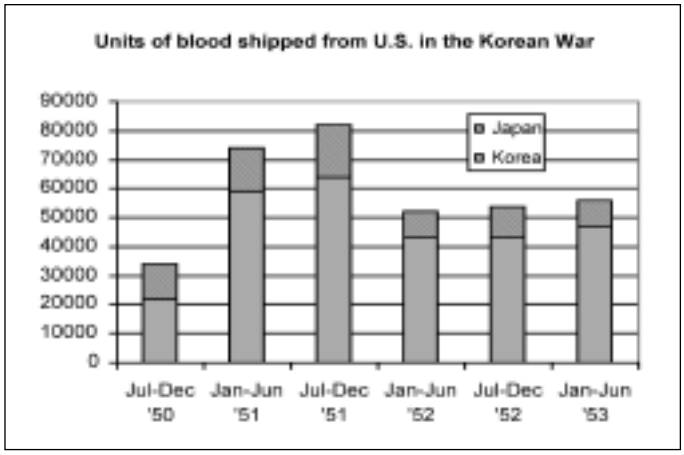

Figure 2. U.S. military blood shipments from the continental U.S. to Korea and Japan. (From Cushing,[7] pages 157 and 158.)

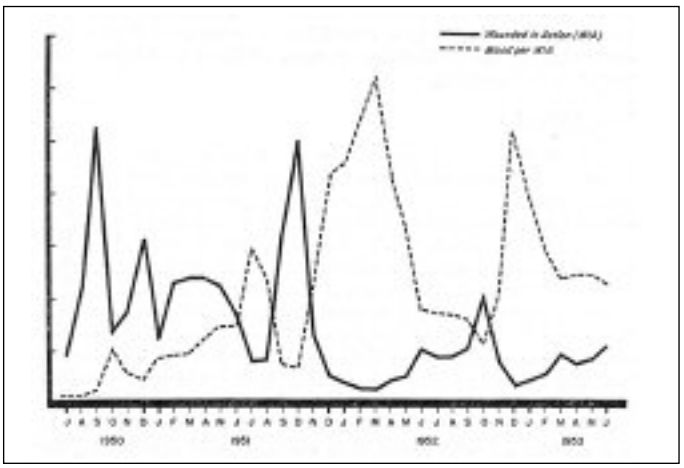

Figure 3. There were 103,284 U.S. casualties wounded in action (WIA) during the Korean War. Casualty rates reached 10,000 WIA per month in September 1950 (Pusan perimeter) and October 1951 (1st Chinese summer offensive). Whole blood stored in ACD with a 21-day shelf-life arrived in country with only 9 days average shelf-life. When casualties decreased below 2,000 WIA per month, much of the blood was not used. (From Cushing,[7] page 159.)

Figure 4. U.S. military blood program in Vietnam. Of the 1.3 million units available, 600,000 were used to treat 330,000 U.S military and some allied casualties. (From Neel,[10] page 155.)

The Cold War. The Cold War never broke out into large-scale fighting, but it occupied the minds of military planners from 1948 to 1991. The major war-planning scenario involved a massive tank battle on the plains of Northern Europe involving four or five Soviet tank armies and smaller but better equipped NATO forces with slowly evolving air superiority. The U.S. military's Air-Land Battle doctrine envisioned 100,000 casualties per day in the opening week of such a war with a requirement for 160,000 units of blood a day. This projected blood demand was more than 4 times the entire U.S. daily production, more than the military had the capacity to move, and more than they had medical personnel to administer. During the U.S. defense buildup of the 1980s, attempts were made to address this perceived shortage of blood in theater. Strategies included increased airhead blood shipping capacity (eventually reaching 14,000 units/day), plans to shift casualty care to NATO allies, deployable blood-handling facilities, and research on alternatives to liquid blood such as hemoglobin-based red cell substitutes and frozen blood. The Berlin Airlift demonstrated that, although virtually all medical supplies could be stockpiled, this was not true of blood, which, at that time, had a shelf-life of 3 weeks.

With this experience in mind, the U.S. military, in conjunction with the RAMC, embarked on a frozen blood program. Investment in developing frozen blood for military use has been ongoing from the middle 1950s to the present and has been funded largely by the U.S. Navy. Attempts to use frozen blood in Vietnam and the Persian Gulf and 10,000-unit frozen blood depots at Sigonella, Italy, and Kaneda, Okinawa, have demonstrated the limits of the technology.[13] At its height, the U.S. military had 60,000 units frozen and had plans to freeze 400,000 units. No plausible scenario to thaw and deliver the units in a timely manner has ever been proposed.

Gulf War. The Gulf War of 1990–1991 consisted of a 6-month build up, a 6-week air war, and 4 days of intense combat. Over half a million U.S. military and support personnel were in theater and 82,000 units of RBCs were sent during that 8-month period.[14] However, only 250 U.S. personnel were injured and only about 250 units of RBCs were used to treat them. Another 750 units were used to treat Iraqi casualties, 6,000 units were returned to the United States, and 8,000 units were given to Romania. The remaining 67,000 units were allowed to outdate over an 8-month period. This outdate rate is equivalent to that observed in Vietnam during quiet periods, but the outdating occurred with RBCs with a 5- or 6-week shelf-life. The outdating also reflected a planning number of four units of RBCs per casualty, a value significantly higher than any historic usage rate.

The Gulf War again saw an attempt to use a frozen RBC system that was now based on centrifugal RBC washing. Approximately 7,000 frozen units were available on two U.S. Navy hospital ships. About 265 units of frozen RBCs were thawed and deglycerolized on the *USS Mercy* in the Persian Gulf, but none were used.[13] There was plenty of liquid RBCs, a lack of previous experience with frozen red cells, and serious questions about the quality of the product. There were also legal restrictions on the use of thawed RBCs more than 24 hours old as an unlicensed blood product, and Navy surgeons and anesthesiologists were not willing to sign the required waivers when licensed products were available.

The small number of U.S. casualties in the Gulf War essentially eliminated the need for triage. Historically, large numbers of battle casualties quickly overwhelmed medical resources. Hospital commanders were forced to sort casualties, assigning the most severely injured to an expectant category. In practice, such casualties typically received only comfort care. In the Gulf War, with few casualties and extensive medical resources, all casualties with potentially survivable injuries received full medical care. One soldier, injured by a munition fragment that entered the perineal floor and exited the anterior abdominal wall, received 52 units of RBCs, 20% of the total amount of blood used in the theater to treat U.S. casualties. Based on this kind of experience, military trauma care planners have placed a high priority on the development of drugs and devices to control massive hemorrhage.

Somalia. The urban firefight in the Black Sea Market area of Mogadishu, Somalia, in October 1993 culminated a week of activity that highlighted both the problems and resources of medical support for small forces in remote locations. At the beginning of the week, the small combat support hospital had 40 units of RBCs and four surgeons.[14] First, a young Marine wading in the ocean near a food-processing plant was attacked by a shark. He suffered massive tissue loss to both legs, but was dragged from the ocean by fellow Marines. By the time he reached the U.S. military medical facilities, he was in profound shock. He received the entire hospital supply of RBCs as well as fresh whole blood. He was returned to the United States brain-dead, as a potential organ donor, accompanied by one of the four surgeons. More blood was ordered from the United States, but before it arrived, two more incidents occurred. In the first of these, a soldier was injured when a mine exploded under her jeep. She received 20 units of fresh, whole O-negative blood donated by her fellow soldiers during surgery. As her surgery was closing, word arrived of the first casualties in the urban firefight. However, the soldiers were trapped in the city in the ongoing street battle. By the time the soldiers were rescued, 16 hours later, hospital personnel had been able to draw an additional 140 units of blood and facilities were ready to handle the 137 casualties. Three surgical teams operated for 36 hours each and used about 70 of the fresh whole blood units. Forty-six of those units were transfused to one soldier with an open pelvic ring injury.

Bosnia. Over a 5-year period, 1995–2000, approximately 5,300 units of RBCs were sent to Bosnia to support the American military's involvement there. Only 79 of these units were used, a usage rate of 1.7%.[15] Most of the unused units were donated to local medical facilities. During the same period, 289 units of frozen RBCs were thawed and deglycerolized. None were used. Other blood components were also made available to forward surgical hospitals. One hundred ninety-six units of fresh-frozen plasma were sent to Bosnia; 13 units were used. Platelets meeting U.S. production standards were also purchased from the Croatian Red Cross. Forty-four such units were shipped and five units used. In several emergency situations, fresh whole blood was collected and 14 units were administered.

Kosovo. In the first year of American involvement in Kosovo, 1,521 units of RBCs were sent and 225 units were used, almost entirely for civilian casualties.[15] In addition, 36 units of fresh whole blood were used, almost all for massively injured and massively transfused individuals undergoing "damage control" surgical procedures. These individuals were also the major consumers of the 47 units of fresh-frozen plasma administered from the 109 units sent and 36 units borrowed from allies.

Civil and Natural Disaster Experience

Texas City Fire 1947. The largest disaster in the United States between the end of World War II and September 11, 2001, was the explosion of two shiploads of ammonium nitrate at Texas City, Texas, on April 16 and 17, 1947. Casualties included 576 killed and 178 injured. Blood was not available in reasonable amounts for this disaster because the national blood system had collapsed after the end of World War II. The national reaction to this event led to the founding of the American Association of Blood Banks and local blood banks across the country.

U.S. Civil Disasters, 1975–2000. Paul Schmidt, former Chief of Transfusion Medicine at the U.S National Institutes of Health Clinical Center and Historian of the International Society of Blood Transfusion, has published a short review of the four U.S. disasters between 1975 and 2000 that required more than 100 units of RBC in the first 24 hours after the event.[16] These episodes were the collapse of a skywalk onto a crowded hotel dance floor in Kansas City in 1981, the crash landing of an airliner at Sioux City, Iowa, in 1989, the bombing of the Mariah Federal Building in Oklahoma City in 1996, and a shooting spree in a high school in Denver in 1999. Total RBC usage in the first 24 hours for the four incidents ranged from 105 to 131 units. In each case, local hospitals had hundreds to thousands of additional units of RBC on hand.

U.S. Natural Disasters, 1975–2000. During the same time period, several major natural disasters occurred. These included two major earthquakes in urban areas of California, a category V hurricane that left a quarter of a million homeless in Florida, and a major volcanic eruption in a remote part of Washington State. The San Francisco earthquake of 1989 was both the most deadly of these episodes, with 68 deaths, and required the most blood, 40 units of RBCs in the first 24 hours. Building codes and zoning restrictions were largely responsible for preventing the higher numbers of casualties associated with similar disasters in less developed parts of the world.

Generalizations from Military and Civil Disaster Experience

Developed countries collect about 1 unit of RBCs for every 20 members of their population every year. Thus, the United States, with a population of 280 million, collects about 14 million units of RBCs each year. Almost all of this blood is used locally to provide routine medical care and to treat victims of injury. Half of all blood used goes to individuals over the age of 65.

RBC usage is about 95% efficient in the United States; that is, about 95% of RBCs units that pass infectious disease testing and are issued by donor centers eventually find a recipient.[17] In the United States, in-hospital transfusion services, where usage is high and the inventory is well managed, RBCs wastage is less than 1%. Losses are highest in remote sites with low usage rates.

Disasters and war both create additional injury victims in need of blood and remove individuals from the donor population. However, in the United States at the height of World War II, neither the diversion of blood nor the removal of donors ever exceeded 9%. It is not clear whether more blood would have been used if it had been collected.

Disasters and war also increase the inefficiencies in a blood supply system. Supplying the U.S. peace-keeping force in Bosnia with RBCs for 5 years from 1995–2000 required about 5,600 units to ensure that the 79 units actually used were available when needed. At first glance this would appear to produce only 1.5% efficiency, but most of the units that were close to outdate were given to Bosnian hospitals as part of the nation-building and support process. The total cost of the blood, about 1 million dollars, was small; the goodwill value of giving it to Bosnian hospitals, where it was vitally needed, was substantial, and the alternatives would have been even more costly. As this blood came entirely from the U.S. Armed Forces Blood Program, it did not impinge on civil blood availability in the United States. In contrast, in the 1990–1991 Gulf War, based on very high—and ultimately mistaken—potential casualty estimates and an inflated planning factor of 4 units per casualty, large amounts of blood were requisitioned from the civil system. Ultimately, 65,000 units of RBCs, 80% of the units sent, never found a recipient and were destroyed.

Choosing the most representative or appropriate usage rates from the past for future planning is both methodologically difficult and contentious. The British Army has slowly increased its estimate of usage rates over the last 50 years, from 1.0 to 1.9 units for each wounded and nonbattle casualty. This change was based on continuing review of experience and anticipated changes in medical practice. The U.S. experience in Vietnam documented a RBC usage rate of 1.3 units for each wounded-in-action or nonbattle casualty. In that cohort, 16% of casualties received whole blood or RBCs. Higher usage rates were reported from smaller cohorts reflecting more restricted populations, such as surgical admissions, or unusual patterns of blood use, as when RBCs were used as a primary resuscitation fluid. Thus, a higher usage rate of 2.6 units for each injured casualty was reported for a cohort, of whom 36% received blood. Based on this experience, the U.S. Armed Forces Blood Program doubled the RBC planning factor from 2 to 4 in the late 1980s. However, this doubling of the blood-planning factor occurred at a time when the total requirement for blood was falling, both because projected numbers of casualties were decreasing with the winding down of the Cold War and because changing transfusion practice was reducing per-patient usage rates.

By the mid-1990s, in response to concern about the safety of the blood supply in the HIV/AIDS era, the culture of surgical blood use was changing markedly. A study by one large Canadian trauma center documented that, by 1995, surgeons were saving more severely injured patients while using less blood than they had used half a decade earlier.[18] More conservative resuscitation strategies, better imaging techniques, and catheter-delivered hemorrhage control all contributed to a reduction in blood use. The recent development and fielding of hemorrhage control bandages based on fibrinogen/thrombin and chitosan, as well as drugs such as recombinant factor VIIa, suggest that hemorrhage control will be more rapid and effective in the future, with even further reductions in the rates of blood use.

As can be seen from the history of 20th century blood use described in the earlier sections of this article, the requirement for blood in large disaster situations is largely determined by the number of injured who survive long enough to present for care and the rate of blood use in providing that care. Clinical series from the Vietnam War largely agreed that only about 16% of casualties reaching care required transfusion. In modern civilian trauma settings, that fraction is even lower. Nine percent of trauma patients presenting to the University of Maryland Shock Trauma Center

in 2000 required transfusion. Data from military blood use in Somalia suggests that modern military surgical teams use about 0.7 units of blood per hour. Civilian trauma centers, exemplified by the Maryland Center, used less than 0.5 units of blood for each hour of operating room time when averaged over the entire 2000 calendar year. This low rate of blood use suggests that, as a current potential military example, should open conflict break out on the Korean peninsula, with a dozen U.S. military surgeons available in country, less than 250 units of blood will be used by U.S forces in the first 24 hours of any local contingency.

Finally, in major disasters of any type, blood availability and usage are often among the less important factors in optimal response. Major earthquakes frequently kill thousands, leave tens of thousands homeless, and destroy or disrupt hospitals, transportation, and utilities, including water. In such situations, the life-saving role of blood becomes small compared with that of meeting basic needs for shelter and clean water.

September 11, 2001

In the first shocking hours after the attacks on the World Trade Center towers and the Pentagon, during which no one knew if the attacks would continue or what the shape of the public health disaster might be, critical decisions in blood management policy were made that, in retrospect, appear ill-judged. The destruction of the World Trade Center towers and the airplane crash and fire at the Pentagon killed 2,800 people and injured 4,000. However, only 258 units of RBC were required to treat the casualties in the first 24 hours.[16] This was very much in keeping with the prior history of blood use in wars and disasters. Nor was there any obvious shortage of blood in local centers. The New York Blood Center handles 1.5 million units a year or 4.5 thousand units a day, suggesting that there were about 18 to 22 thousand units available in the New York metropolitan area. (Blood availability in metropolitan areas can be estimated from annual usage rates, assuming that blood centers maintain a 1- to 2-day supply and hospitals keep a 3-day supply for a total of 4 or 5 days worth of RBCs on hand for use or sharing.) In Washington, DC, the Chesapeake and Potomac Red Cross, Inova Blood Services, Washington Hospital Center, the military hospitals, and the National Institutes of Health all run blood donor programs and collect about 1,500 units a day in aggregate. Calculation suggests about 6 to 8 thousand units should have been available, and a survey at the time found 12,000 units.[16] There was no shortage of RBCs.

What happened, however, was that at midmorning on September 11, the Red Cross halted the distribution blood products from its regional centers and announced that it did not know when distribution would be resumed. This action forced local hospitals in the Washington-Baltimore region to look for new sources of blood. Many institutions attempted to "top off" their inventory at a time when transportation services were shutting down. Meanwhile, in response to the tragedy, donors came in droves. Within hours of the attacks, the lines of donors themselves were impinging on blood centers' ability to provide what services were needed beyond collection. Despite this, and the fact that it became clear within hours that there was no shortage of blood, the Red Cross continued to collect extra donations for weeks. The justification for this was the building of a "National Blood Reserve," first of 7–10 days of liquid blood and later of frozen RBCs.[19] As the extra liquid RBC units approached expiration, the Red Cross tried to sell them at full price. Other suppliers were giving away excess units. In the 6 weeks following the attacks, the blood supply system experienced a classic market supply-and-demand crisis: a threat to supply triggered at first hoarding and then glut. Ultimately, almost 600,000 extra units of blood were collected and over 300,000 units were destroyed.

In response to this very public debacle, the U.S. Department of Health and Human Services (DHHS) Advisory Committee on Blood Safety and Availability (ACBSA) recognized the urgent need to improve preparedness of the domestic blood system to address natural and man-made disasters, including acts of terrorism. The committee recommended that the American Association of Blood Banks Interorganizational Task Force on Domestic Disasters and Acts of Terrorism should coordinate the national response of the blood community in the future. The Task Force has subsequently emphasized the importance of functioning infrastructure.[20]

Conclusions

The ideal number and optimal physical location of RBC reserves in a blood supply system are open questions. Donor centers work hard to recruit adequate numbers of donors, and sometimes they do not meet self-imposed quotas. Large reserves at the donor center allow regular shipment and response to emergencies. On the other hand, large reserves at a regional center simply mean that most users are receiving older blood. Large reserves at hospitals support surges in usage but frequently lead to waste. Despite seasonal shortages, supply is generally good. Data from the U.S. National Blood Data Resource Center and the American Hospital Association show that 75–84% of U.S. hospitals cancelled less than one surgery annually for lack of blood in the years 2000 to 2002. On the worst of days, there are at least 100,000 units of RBC on the shelves of U.S. blood centers and hospitals, a 3-day supply, always presuming that this supply can be delivered where it is needed.[20] Increasing blood reserves may decrease stress on the collection system in a crisis, but the problem of transporting those reserves during crises that often include disruption of the transportation system is at least as important. Business practice regarding other perishable products—cut flowers, seafood, fresh vegetables—is very focused on optimal movement of product from producer to retailer and consumer. Blood systems planners may need to refocus their attention from a dominant concern with collection to include consideration of improved distribution and total system inventory management.

Disasters are best handled when local emergency services perform simple and clearly understood functions well under stressful circumstances and then are able to smoothly incorporate outside assistance as it becomes available and is needed. At baseline, at least in blood banking and supply, routine procedures should be used at all times. At this time, there is no evidence that frozen blood or any other nonstandard blood product provides any advantage over liquid RBCs in large-scale disaster situations. Indeed, the labor-intensive, facility-intensive (including functional electric power systems), and product-intensive nature of frozen blood systems makes them highly impractical in such situations. (Frozen blood procedures waste 20–30% of RBCs and the units are short-lived.) Realistic regional and national disaster drills should concentrate on mobilizing small amounts of liquid RBCs quickly. One hundred to 200 RBCs units can meet the needs of any of the national level disasters that have

occurred in the U.S. over the last 25 years, as long as local stocks are repleted appropriately. International incidents have the same scale. The U.S. sent 160 units of RBCs to Kenya and Tanzania to help with the care of the victims of the embassy bombings and to replenish local supplies, but they arrived more than 24 hours after the incident. Local supply was most important in these time-critical situations.

Robust, standardized local and regional blood banking systems provide reservoirs of trained workers and well-equipped staging facilities. Combined with thoughtful, flexible, evidence-based emergency and contingency planning, such systems are more than able to supply blood needs in major wars and disasters. Local availability of high-quality liquid RBCs remains the critical component of blood support for emergencies.

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Synthetic Blood: Myth or Reality?

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Learning Objectives: 1) To describe the current status of blood use and availability in the United States, 2) to identify oxygen-carrying solutions possible to use as alternatives to blood, 3) to review clinical applications of hemoglobin-based O_2 carriers, and 4) to support a hypothesis that hemoglobin based oxygen-carrying solutions could replace a two-unit packed red blood cell infusion for orthopaedic trauma.

Abstract

Synthetic blood may be the solution to a predicted shortfall of packed red blood cells that will be required because of an aging population, increased blood use, and decreased allogeneic collection. With the cost of blood escalating, and blood donation and demand converging, an alternative blood supply must be planned. Two-unit packed red blood cell transfusions account for nearly one-third of red cell use in trauma; approximately 60% of blood is given within the first 24 hours of admission after injury. Oxygen-carrying solutions could be used to avoid the two-unit transfusion for acute blood loss in trauma, for field resuscitation, and when blood is unavailable or refused. More clinical trials are needed for hemoglobin-based O_2 carriers, which provide benefits for trauma patients of no crossmatch, prolonged room temperature storage, volume expansion, stimulation of erythropoeisis, improved rheology in ischemia, and facilitated oxygen diffusion.

Blood Use in the United States

At the Shock Trauma Center in Baltimore in the year 2000, 5,632 trauma patients were admitted, of whom 9.1% (514) received 5,311 units of blood. Figure 1 shows that 72% of the total units of blood (designated by the bar along the top of the graph) were administered to 144 severely injured patients who received more than 10 units. These patients had a mean Injury Severity Score of 32 (30 lived; 35 died) and 38% mortality. Among the remaining 370 patients who received blood, the most frequent mode of infusion was a two-unit red cell transfusion. The 1998 blood transfusion data from Ben Taub Hospital, another major trauma center in Houston, Texas, shows a similar picture. The most frequent mode of

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