Convergence
A Journal for Young Researchers

ORIGINAL REVIEW

Received: 11-19-25; Accepted: 2-4-26;
Managing Editor: Jonas Katona;
Action Editor: Kathryn Grive

Methods to Alleviate Blood Shortages and Blood Deserts

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Abstract

Blood transfusions are essential for cancer treatments, surgeries, emergencies, and other medical conditions. However, there is an insufficient amount of people donating blood because of seasonal illnesses, less blood drives, and lack of donation awareness. Blood shortages are especially prominent in low- and middle-income countries and rural locations, often referred to as "blood deserts" due to the limited access to blood. This paper analyzes various methods to alleviate these issues. Potential solutions are split into four categories: blood substitutes (hemoglobin-based oxygen carriers and stem cell-derived substitutes), hospital blood management (blood conservation policies and computational models for blood inventory and transportation efficiency), blood donation awareness (online campaigns and in-person efforts), and blood accessibility (drone delivery, autotransfusion, and walking blood banks). For each solution, their benefits, drawbacks, and current progress are examined. Findings indicate that all methods have been extensively developed and are promising, but hemoglobin-based oxygen carriers, hospital blood management, and blood drone delivery in particular are likely to be most impactful. The paper proposes an effective multi-faceted approach that prioritizes these three methods, while also reinforcing them with supplemental strategies. This will ensure the main aspects of shortages, supply, demand, and accessibility, are targeted. The paper recommends that further steps including clinical trials, regulations, increased funding, and technological refinements be made. Ultimately, this paper aims to increase awareness and support for the efforts to improve blood shortages.

Keywords: blood shortage, blood deserts, blood transfusion, blood substitutes, hemoglobin-based oxygen carriers (HBOCs), stem cell-derived red blood cells, hospital blood management, blood supply chain, blood donations

1. Introduction

The need for blood is critical. Blood products are used everywhere in the medical field, including surgeries, treatments for diseases, and emergencies. In fact, the American Red Cross reports that in the U.S., every two seconds an individual requires blood ("US blood supply facts," 2025). However, there is not enough blood supply to serve these needs. Low- and middle-income countries face an annual shortage of 102 million units of blood, and every country in sub-Saharan Africa and South Asia is struggling with these issues (Raykar et al., 2024). Hundreds of millions of people live in blood deserts, which are areas where blood cannot be given in at least 75% of cases where it is needed.

With natural disasters, seasonal illnesses, and the COVID-19 pandemic forcing schools and workplaces to cancel blood drives, blood shortages around the world were exacerbated (Sahu et al., 2020). The American Red Cross declared its first-ever national blood crisis in January 2022 (American Red Cross, 2022). The 42-day shelf life of blood is also another contributor to the limited supply (Zaleski, 2024). To make things worse, the general population, especially young donors, is unaware of the importance of blood donations or has misconceptions about donating blood (Korkut, 2023).

To solve the issue of blood shortages, it is imperative to look at the potential strategies that are being developed and implemented. This paper analyzes solutions targeting various aspects of blood shortages, highlights optimal approaches, and provides suggestions for involved parties.

2. Methodology

The primary databases used to identify sources for this narrative review were PubMed and Google Scholar. The search engines Google and Safari were also utilized to find news articles and websites due to the web's vast network of resources. The reference lists of included sources were examined to select additional papers. Search engines and catalogs from the University of Pittsburgh's Health Science Library System were also utilized to find e-books and journals. Staff members from the University of Pittsburgh's Falk Library of the Health Sciences were also consulted to assist with the search process.

The search terms utilized to obtain sources were as follows: blood shortage, blood desert, blood transfusion, blood substitute, blood alternative, blood bank, blood management, blood inventory, blood donation, blood awareness, blood supply, drone blood delivery, walking blood bank, and autotransfusion. The following inclusion criteria were used to evaluate whether each source should be considered for the report. First, the source had to align with the purpose of the research. The source needed to be a peer-reviewed paper or article from a reputable organization, such as the American Red Cross, NPR, Smithsonian Magazine, or Science. Finally, the source had to be published between 2015 and 2025. A notable limitation of this review is that most sources included are from the United States, which may not fully capture how applicable solutions are in other parts of the world.

After reviewing all sources, potential methods were recorded and originally separated into long-term and short-term solutions. This decision was made due to an observation that long-term solutions often focused on the lack of blood, while short-term solutions targeted the difficulty to access blood. However, this categorization was later eliminated, and solutions were instead separated into four specific categories: blood substitutes, hospital blood management, blood donation awareness, and blood accessibility. Each category targets different aspects of the blood shortage issue and has different impacts, so this categorization facilitates comparison between the various solutions. The main aspects that were targeted by solutions were determined as supply, demand, and accessibility. Each method was analyzed on their advantages, weaknesses, and current progress. Based on this information, the most promising solutions were identified, and recommendations were developed.

3. Blood Substitutes

A very promising solution to blood shortages is blood substitutes, because it eliminates the need for human blood. One of the most favorable types of blood substitutes is hemoglobin-based oxygen carriers (HBOCs), in which hemoglobin is used to transport oxygen around the body, just like regular blood does (Sederstrom, 2025). HBOCs do not carry infections, can be used for any blood type, and can be stored for two to five years. In the U.S., the Department of Defense is funding researchers who are developing an HBOC called ErythroMer. ErythroMer is made from recycled human hemoglobin taken from expired blood, which is encased in a phospholipid bilayer membrane to create cells ("ErythroMer," 2025). This membrane prevents the hemoglobin from collecting too much nitric oxide, which can lead to vasoconstriction and high blood pressure. The molecule 2,3-DPG controls how much oxygen is taken up and released by the cells. ErythroMer is stored in a freeze-dried powder format and can be mixed with water in one to two minutes, making it convenient for storage and transportation (Stein, 2025). This can allow ErythroMer to be used in places where blood is not readily available, like rural areas, car crashes, and the battlefield. Preclinical testing on animals has been successful so far, and researchers are working towards human clinical trials (Zaleski, 2024).

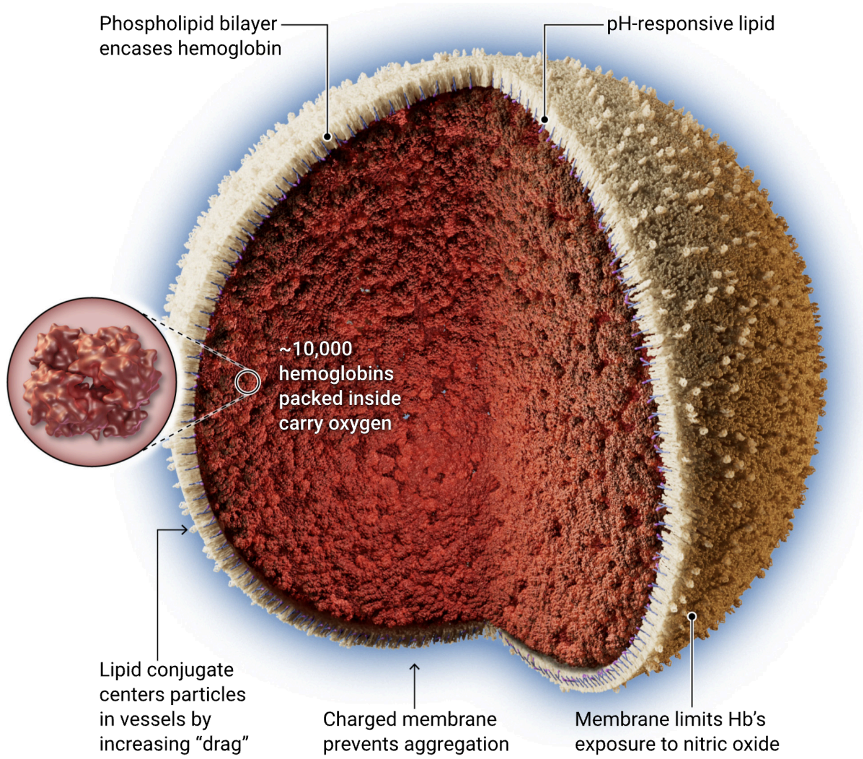

Figure 1: Diagram of an ErythroMer cell showing the lipid membrane surrounding the hemoglobins. The image shows the multiple positive benefits the membrane offers, including restricting the amount of nitric oxide collected. (Zaleski, 2024).

Another HBOC is in the works in Japan, where researchers have taken a similar approach. They created hemoglobin vesicles (HbVs)- liposomes that wrap the hemoglobin- and have performed the first clinical trial on humans with the synthetic blood (Azuma et al., 2022). Mild side effects like fevers and rashes occurred, but there were no serious issues with blood pressure, heart rate, or oxygen levels. The half-life of an HbV is around eight hours, and it can be increased with a higher dose (Sakai et al., 2022). This is enough time for the HbVs to circulate oxygen in emergencies, like a patient in hemorrhagic shock. Since the first phase was a success, scientists are now planning for larger trials to further test effectiveness and safety.

Other approaches to blood substitutes include using human pluripotent stem cells (hPSCs) to make red blood cells. These stem cells are reprogrammed adult cells that can differentiate into specialized cells with specific functions. They can also replicate themselves to make more red blood cells. Scientists are researching how to differentiate stem cells into red blood cells to transfuse into patients (Lee et al., 2023). The process of creating blood cells, called erythropoiesis, is done in the bone marrow. During erythropoiesis, growth factors push a cell through the stages of development. Similarly, researchers are using growth factors to transform stem cells into red blood cells. To facilitate the process, stem cells are placed in environments that mimic human body conditions.

There are many hurdles that come with red blood cell development, including issues with the nucleus of a red blood cell. Normally, red blood cells do not contain nuclei because they are ejected to accommodate the amount of hemoglobin and let the cells squeeze through tight blood vessels. But the process of ejection, called enucleation, often doesn't occur in the lab, making the cells not functional (Lee et al., 2023). Another problem that researchers encountered was the red blood cells producing fetal hemoglobin. Once red blood cells mature, they need adult hemoglobin, but this is difficult for scientists to facilitate. The overall process of producing red blood cells from human pluripotent stem cells is very slow and expensive, making it difficult to replicate it on a large scale (Twilley, 2025). With the development of gene editing technologies and plans to continue testing, there is still hope for a blood substitute to be made with stem cells.

A big hurdle for blood substitutes is implementing them into medical practice. Many patients and hospitals may be hesitant to use substitutes, so it is important to inform the public about their effectiveness and safety. Public awareness campaigns, transparent clinical data, and support from trusted health organizations can help integrate blood substitutes smoothly into healthcare.

4. Hospital Blood Management

Hospital blood management targets a different facet of blood shortages: demand for blood. To determine the most efficient methods to manage blood, researchers have developed a stochastic mixed-integer linear programming model that provides the best inventory policies for hospitals and blood centers to follow based on supply, demand, and various other factors (Shih & Rajendran, 2020). The model found that when supply and demand fluctuate a lot, the supply chain costs, number of shortages, number of expired units of blood, and inventory holding levels significantly increase. Another flexible, robust mathematical model was created to find solutions to issues in the blood supply chain (Khalilpourazari & Hashemi Doulabi, 2022). The model determined the most cost-efficient and time-saving routes for transporting blood, taking into account uncertainties and disruptions like earthquakes. If hospitals and blood banks implement these models, they can plan ahead for severe blood shortages, waste less blood products, deliver blood quickly, and save money. In the future, machine learning and other novel types of models may be able to enhance inventory and supply chain management alongside current models (Javadzadeh Shahshahani et al., 2024).

The COVID-19 pandemic forced many hospitals to adopt blood management strategies so that blood can be conserved as much as possible. The Federal Drug Administration relaxed blood donor eligibility requirements and deferred donors for three months instead of the usual twelve months (Ngo et al., 2020). Elective surgeries and invasive procedures were postponed, reducing the surgical volume of blood by 71.7%. It is also beneficial to use a hemoglobin trigger of 7g/dL or lower in nonbleeding patients, meaning that blood should only be transfused if the hemoglobin level is less than or equal to the trigger level. Not only does this effectively conserve blood products, but it can also lower the number of infections, rebleeding, and cardiac incidents. This lower hemoglobin trigger does not have critical consequences for patients. A study found that hemoglobin triggers of 7-8g/dL halved the use of blood products, and had similar mortality and organ dysfunction rates as more liberal hemoglobin triggers of 10-11g/dL (Palmieri et al., 2017).

Unnecessary platelet and plasma transfusions should be avoided as well, since they can be overestimated and even increase the risk of blood clots and death (Ngo et al., 2020). Pharmaceutical products, including desmopressin and antifibrinolytics like tranexamic acid, can also be used in hospitals to reduce bleeding. In one trial testing tranexamic acid in coronary artery surgery, the experimental group using tranexamic acid transfused 3663 less units of blood than the placebo group (Myles et al., 2017). Iron supplements and erythropoiesis-stimulating agents are shown to increase hemoglobin levels. Frozen blood components like cryopreserved red blood cells and plasma act as alternatives to blood as well (Gasparovic Babic et al., 2024). There are a variety of other substances that can be used to prevent wasteful blood transfusions.

A study in Iran identified the leading causes of blood wastage, including expiration, hemolysis, contamination, blood bag leakage, and temperature variations in storage or transportation (Javadzadeh Shahshahani et al., 2024). The study implemented a procedure to reduce blood wastage in Iran and analyzed the wastage rate before and after implementation. This procedure consisted of methods like sending surplus blood from hospitals to other blood centers, monitoring blood temperatures during transport, maintaining centrifuges to reduce blood contamination, and continual training courses for medical staff to properly handle blood products. After the intervention, researchers found that the overall blood wastage rate decreased by 36.86%.

Adopting hospital blood management strategies can be a time-consuming process due to the extensive amount of planning, coordination, and approval it requires. Governments should introduce programs to streamline the implementation of blood management policies. These programs could include standardized guidelines and staff training tools to assist hospitals with the process.

5. Blood Donation Awareness

The simplest route that many are working on right now is blood donation awareness. The World Health Organization reports that 90% of eligible blood donors are not donating (Gasparovic Babic et al., 2024). The aging population is also contributing to the low number of donations. Young donors have the potential to make a huge impact in improving blood shortages if they donate blood. To target this audience, a popular approach that is being taken is the use of social media. Involving celebrities in social media campaigns can attract many people and be extremely impactful (Dorle et al., 2023).

Regular social media campaigns on Instagram are not the only option, though. Apps for scheduling donations and messages on WhatsApp to donate blood can motivate young individuals to take action. A Facebook tool that finds local blood centers was found to increase donations by 4% and first-time donors by 18.9%. Post-donation images shared online, streamlined procedures, comfortable facilities, and incentives like discounts and recognitions encourage people to keep donating.

Promoting blood donations can also happen in-person. Community events like birthday parties, cultural gatherings, and annual events are excellent ways to engage the public (Dorle et al., 2023). Partnering with organizations, businesses, and colleges can help blood donation campaigns be sustainable, and hosting blood drives in these spaces can create immense positive impacts. In medical offices, practitioners can raise donation awareness by putting up posters, wearing badges, and providing information sheets to patients (Jouannin et al., 2023).

In addition, education about the health benefits of blood donations and safety standards may influence the public to donate blood. Some individuals are hesitant to donate because they have misconceptions about disease transmission, weight loss, high blood pressure, and other risks (Korkut, 2023). However, pathogen reduction technologies and nucleic acid testing make blood extremely safe to donate, and donating actually reduces the risk of cardiovascular disease, cancer, clot formation, and high blood pressure (Gasparovic Babic et al., 2024). Campaigns, websites, and fact sheets should highlight these facts to reassure donors.

6. Blood Accessibility

Blood accessibility solutions are extremely beneficial to blood deserts, which require rapid and accessible approaches to be utilized. Organizations like the Blood DESERT Coalition have suggested and advocated for certain strategies, one of them being drone delivery of blood (Raykar et al., 2024). Drone delivery is much faster than transporting blood by ambulance since it can bypass rough terrain, heavy traffic, and slippery roads in bad weather. Drones have been used to transport blood and medications in both high- and low-income countries like Switzerland, the U.S., Ghana, and the Dominican Republic. Due to their fast delivery times, drones have been proven to reduce blood wastage by 67%, cutting down the number of expired products by 140 from 2017 to 2019 (Levy, 2022).

One company called Zipline partnered with the government of Rwanda to make blood delivery efficient, which had been difficult due to the poor road infrastructure and the mountainous terrain. Hospitals can order blood products through WhatsApp, SMS, or phone call (Amaechi et al., 2020). Once an order is received, it is packaged at one of Zipline's distribution centers and sent out in a drone. The product is delivered by parachute in a designated space, hospital staff are notified through text message, and the drones are returned to the distribution center. The flight routes are predetermined, and the drones are able to fly autonomously, so drone pilots are not necessary. The drones collect weather data and are trained through machine learning to avoid obstacles ("Zipline," 2025). They are even equipped with backup sensors, extra propellers, and an emergency parachute landing system to ensure safety. Personnel monitor the drones in control towers for safety purposes. In a study comparing drones and ambulances, drones had a mean delivery time of 49 minutes, while ambulances had a median delivery time of 120 minutes (Nisingizwe et al., 2022).

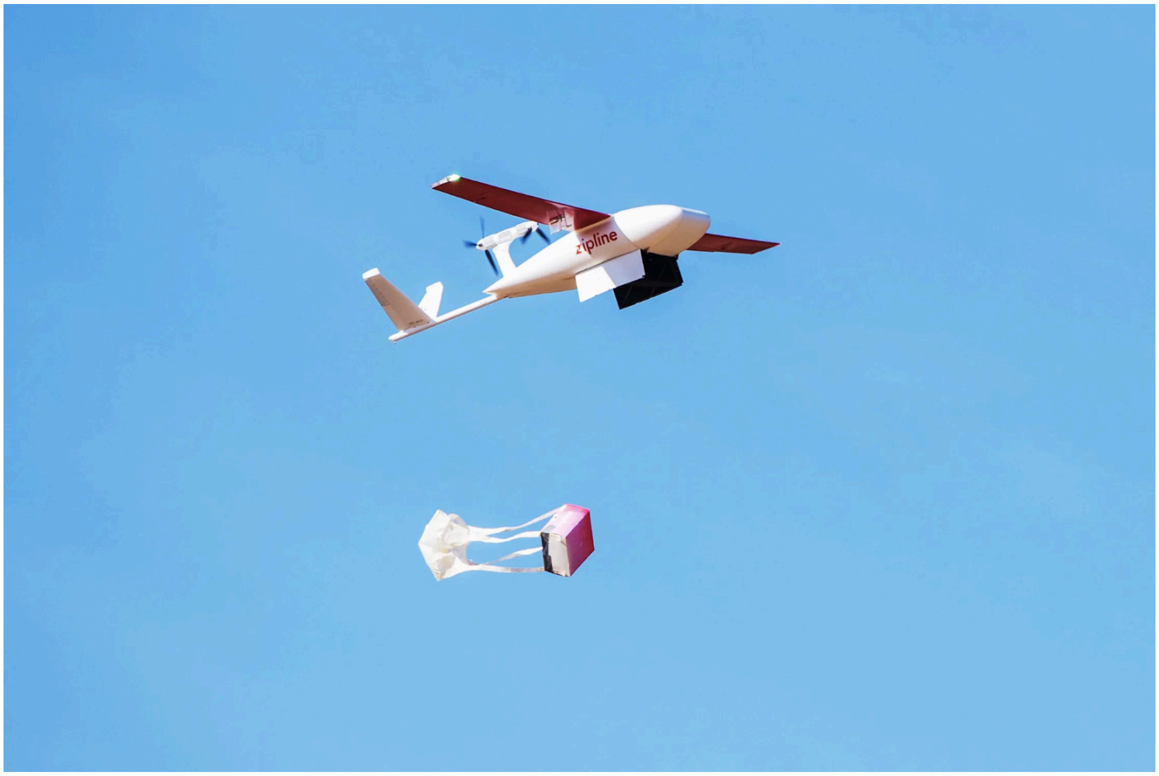

Figure 2: Zipline drone delivering a blood product. (Levy, 2022).

An important factor for blood drone delivery is temperature stability. Blood temperature deviations can result in hemolysis, bacterial contamination, and reduced oxygen-carrying capability. In a study testing another type of drone, the temperature of the blood did not change much throughout the trips, with temperature variations being no more than 1°C (Homier et al., 2020). Temperatures were able to be maintained by bags containing phase-changing material. In regard to costs, drone transportation is more expensive than ground travel, with drones costing $17.74 per minute, while ambulances cost $9.05 per minute (Zailani et al., 2021). Nonetheless, the large amount of time that was saved from the drone delivery offset the costs and therefore proves drones to be more cost-effective.

Researchers are looking to make improvements in drone technology, including better payload capacities, batteries, and temperature regulation. Currently, the maximum payload capacity reported is 6.4 kg, but it is expected that with more advancements, drones will be able to carry heavier weights (Homier et al., 2020). Batteries also need to be lighter and longer-lasting in order to increase payload and distance capabilities (Gauba et al., 2025). A device called Smart Capsule that utilizes artificial intelligence has been developed to monitor and regulate temperatures (Liu et al., 2022). However, even with this technology, hemolysis and pH levels still need to be analyzed after the delivery of a blood product, which can take up to 30 minutes. Engineers are working on implementing a sensor that detects hemolysis and pH levels into the Smart Capsule to reduce the time it takes for blood to get to a patient.

Other than drones, scientists are turning to autotransfusion during surgery, which involves collecting the patient's blood using a machine, filtering it to remove clots and particulates, and returning it to them ("Hemafuse," 2025). Autotransfusion reduces the amount of allogenic blood needed, eliminates the need to match blood types, cuts down costs from testing, processing, and storing blood, and shortens transfusion time. Studies have also shown that autologous erythrocytes perform better than allogeneic erythrocytes and that autologous blood has a lower risk of postoperative infection than allogeneic blood does (Schmidbauer & Seyfried, 2022). Moreover, using a patient's own blood for surgery allows blood products to go to the people with diseases like leukemia and anemia who urgently need blood for treatment (Bajaj, 2024).

Autotransfusion is most often used for hemothorax, or blood in the pleural cavity, and obstetric hemorrhages (Palmqvist et al., 2022). One study has shown that patients who received autotransfusion in cesarean delivery were 68% less likely to need allogenic blood transfusions (Pfalzgraf et al., 2025). Data has also demonstrated that autotransfusion during cesarean delivery led to smaller hematocrit change and a 74% decrease in new anemia development. In terms of cost, using autotransfusion for patients at high risk of obstetric hemorrhage is most cost-effective, but using autotransfusion for all deliveries is not.

Autotransfusion doesn't come without concerns, though. Autotransfusion devices can be very expensive, with the Cell Saver device costing $20,000 (Bajaj, 2024). Low- and middle-income countries may not be able to afford the technology to perform autotransfusion. However, some developing devices are getting cheaper, like Hemafuse, which sells for $120. Hemafuse's process takes ten minutes, which makes it easy to use in low-resource settings (Hansman, 2015). Another device that is in the works at Christian Medical College Vellore uses gravity to remove the blood from the patient, is disposable, and may cost even less than Hemafuse. Neither this device nor the Hemafuse runs on electricity, which makes them perfect to use in remote areas and blood deserts. Other autotransfusion devices that are being studied include the Tanguieta funnel, the postpartum hemorrhage autotransfusion device, and the leukocyte depletion filter (Palmqvist et al., 2022).

Other autotransfusion issues include the risk of contamination of patient blood, the low number of individuals who are trained to operate autotransfusion devices, and the lack of information and widespread use of autotransfusion (Palmqvist et al., 2022). One study found that autotransfusion techniques are not well documented or described in the literature. It also stated how the shortage of supplies and inadequate training led to low utilization in countries like Zambia. More research, guidelines, and training resources are needed to promote the use of autotransfusion.

The last solution is walking blood banks, systems where doctors collect blood from community members, test the blood for diseases at the site of donation, and directly transfuse the blood into patients (Raykar et al., 2024). Even healthcare workers can donate their blood if the situation is urgent. With this practice, blood banks, refrigerators, and transportation are not required. Moreover, the blood is at an ideal temperature inside a donor's body, which gets rid of the concern for hemolysis and contamination (Panella, 2025). The U.S. military also uses walking blood banks in war zones as a safe and effective method to give blood. Walking blood banks can be particularly impactful in rural areas, mass shootings, and other incidents (Brigmon et al., 2024).

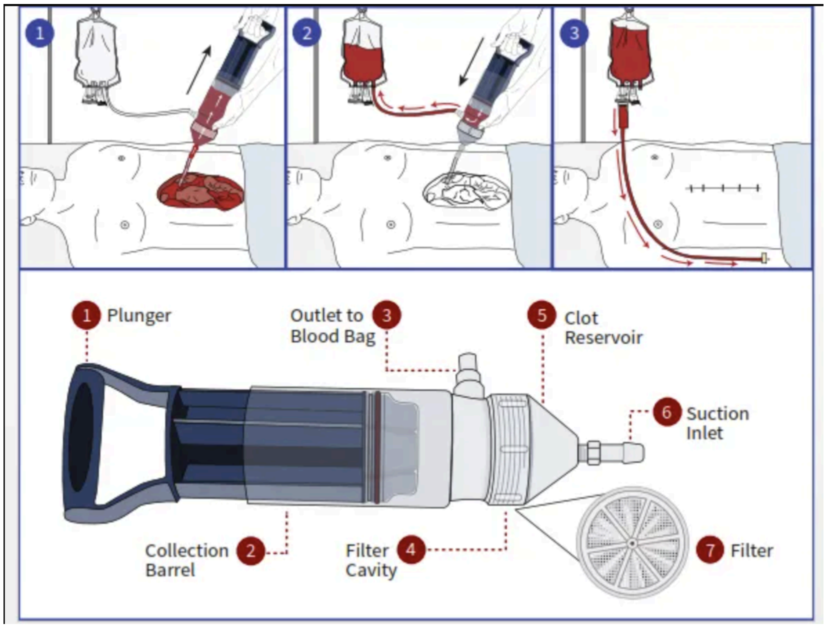

Figure 3: Depiction of the Hemafuse autotransfusion device's components and steps for utilization. (Hansman, 2015).

Although it is possible to draw blood on the spot, it is often easier and more efficient to have a prepared donor pool that would be willing to donate blood (Degueldre et al., 2024). Volunteers in this pool would be pre-screened to test for diseases like HIV, hepatitis B, and hepatitis C before an emergency. Donors who have low-titer type-O whole blood are often used because the blood does not have A and B antibodies, making it compatible with all blood types (Coss, 2021). Another alternative, instead of using whole blood, is component therapy, which involves transfusing a 1:1:1 ratio of packed red blood cells, fresh frozen plasma, and platelets (Gaspary et al., 2021). However, component therapy is difficult to maintain, especially in rural and military settings.

Many countries have banned walking blood banks because of the risk of transmitting dangerous diseases. Even though rapid diagnostic testing for these diseases can screen with 98-99% accuracy, the World Health Organization still strongly advises against using these tests (World Health Organization, 2023, p. 9). Doctors who support the stance of the World Health Organization say that extreme and diverse conditions in countries in Africa and Asia can lead to inaccurate results. Additionally, technicians in rural areas might not have the experience to correctly run these tests. Other healthcare professionals argue that people in emergencies may be on the brink of death, and in an environment without alternatives, it is better to run the risk of disease than to let the patient die (Bajaj, 2024). Improving diagnostic testing of blood may help integrate these techniques in blood deserts. Further discussions and regulations about the ethics of walking blood banks will be necessary in order to ensure the safety of patients. Governments and health agencies should define the circumstances under which walking blood banks may be permitted and establish measures to ensure their safety.

It is important to keep in mind that these accessible solutions can be hard to maintain, are not yet as efficient as possible, and do not directly address the issues of blood supply and demand. Therefore, these methods should not serve as alternatives to the other categories, like blood substitutes or blood donation awareness, but instead be supplements to further improve blood shortages and deserts (Raykar et al., 2024).

7. Discussion

The solutions mentioned in this paper are monumental strides on the path to solving blood shortages. The research and progress that have been made show signs of future success. However, there are still concerns regarding each solution. For instance, there are multiple blood substitutes that will be competing against each other, so it will be important to discuss which option will be most effective, considering costs, accessibility, safety, and other factors taken into consideration.

Blood management models using machine learning should be developed for more advanced and accurate predictions. It may also be a challenge for hospitals to set up blood management systems with the extensive amount of time it will take. Hospital executives should consider implementing conservation policies as soon as possible before blood shortages worsen. Similarly, it takes a lot of effort to encourage people to donate blood due to misconceptions about health risks. The public should raise more awareness about blood shortages and keep donating blood to maintain the supply before shortages are exacerbated. Blood banks and healthcare organizations should initiate donation education campaigns and increase blood donation promotion on social media platforms like Instagram, WhatsApp, and Facebook.

Safety concerns are a huge issue for walking blood banks and autotransfusion due to risks of disease transmission and blood contamination, respectively. Global health experts should discuss the safety of walking blood banks and formulate policies to ensure their safety. Distributing guidelines and resources on how to operate autotransfusion devices will allow for safe and widespread use. Furthermore, substantial costs hinder the implementation of blood delivery drones and autotransfusion devices. Investors and government agencies should fund these methods so that they can be put into practice.

Lastly, studies and technological advancements will benefit all solutions mentioned in the paper. Enucleation and adult hemoglobin production need to be facilitated in stem-cell-derived substitutes. Payload capacity, batteries, and temperature regulation need to be improved in blood drone delivery. Autotransfusion devices need to be tested further to avoid blood contamination. All of these issues can be addressed with further testing and clinical trials. Table 1 summarizes the suggested improvements for each method.

After reviewing all of the potential solutions, this paper finds that hemoglobin-based oxygen carriers, computational blood management models, hospital blood management policies, and blood drone delivery will be most effective at alleviating blood shortages. Table 2 evaluates these four primary methods against key criteria, including progress, potential impact, benefits, barriers, and targeted aspects of shortages (supply, demand, and accessibility). It should be noted that together, these primary methods target all three aspects. By addressing multiple aspects, blood shortages can be solved in the most efficient manner possible.

Table 1: Recommendations for blood shortage solutions

Category	Potential Solution	Recommendations
Blood substitutes	Hemoglobin-based oxygen carriers	Perform larger clinical trials on humans; decide which HBOC is most effective
	Stem cell-derived blood substitutes	Facilitate enucleation and production of adult hemoglobin
Blood management	Computational blood management models	Utilize machine learning to create new models and improve existing ones
	Hospital blood management policies	Implement blood conservation policies in healthcare facilities
Blood donation awareness	In-person donation awareness	Spread more information about blood donations; continue to donate blood
	Online donation awareness	Utilize social media to promote blood donations
Blood accessibility	Blood drone delivery	Improve payload capacity, batteries, and temperature regulation; increase funding
	Autotransfusion devices	Distribute guidelines and training resources about autotransfusion device operation; research how to avoid blood contamination; increase funding
	Walking blood banks	Create regulations to ensure safety

Table 2: Evaluations of primary solutions for blood shortages

Method	Progress	Potential Impact	Benefits	Barriers	Targeted Aspects
Hemoglobin-based oxygen carriers	ErythroMer preclinical testing on animals has been successful, and HbV human clinical trials showed no serious effects	May eliminate the need for blood transfusions	Compatible with all blood types, do not transmit infections, shelf life of 2-5 years, easily stored and transported, used in inaccessible areas, long half-life	ErythroMer needs to be tested on humans, and HbV safety needs to be tested with larger clinical trials	Supply, accessibility
Computational blood management models	A stochastic mixed-integer linear programming model and a flexible robust mathematical model were created	Cuts down blood wastage, reduces transportation time and money	Determines the most optimal blood inventory policies for hospitals, and suggests the best time-saving and cost-efficient blood transportation routes	Can be improved further with new models and machine learning	Demand, accessibility
Hospital blood management	Hospitals have implemented	Cuts down blood wastage	Lowers the amount of infections,	Takes time and discussion for	Demand

policies	policies and saw effective results		rebleeding, and cardiac incidents	hospitals to implement policies	
Blood drone delivery	Countries like Rwanda and Ghana have seen success with drone delivery	Reduces transportatio n time and number of expired blood products	Bypasses rough terrain, can fly autonomousl y, maintains blood temperature, is cost-effective	Payload capacities, batteries, temperature regulation, and cost effectiveness can be improved even further	Accessibility

Hemoglobin-based oxygen carriers are arguably the most developed type of blood substitute, with human clinical trials underway. They are cheaper than stem-cell-derived blood substitutes and may one day replace the need for human blood. With the rise of machine learning, computational models will make critical predictions and decisions to improve blood supply chain efficiency. By implementing blood-conserving policies, numerous healthcare facilities and case studies will continue to significantly reduce the use of blood. Blood drone delivery will drastically increase access to blood in rural and remote areas. With successful programs in countries like Rwanda and Ghana, there is hope that drone delivery can be implemented across the globe.

Other methods mentioned in the paper, such as walking blood banks and in-person and online blood donation campaigns, are still highly encouraged to supplement the primary approaches. Although not as impactful as the primary methods, supplementary methods still make essential contributions to shortage alleviation efforts. Table 3 evaluates the supplementary strategies against the key criteria used in Table 2 for comparison.

One example where primary and supplementary solutions could work together is if hemoglobin-based oxygen carriers become available for use. It would be a gradual process to incorporate blood substitutes into medical care, so blood donations would still be necessary for the first few years. In this case, utilizing blood donation awareness would be beneficial to maintain the blood supply while HBOCs roll out. Additionally, autotransfusion can be incorporated into hospital blood management policies to further reduce the amount of blood products used.

A more complex situation arises in natural disasters or on the battlefield, where HBOCs, drone delivery, and walking blood banks can be used together or separately, depending on several factors. Firstly, all three methods are limited by their supply, so if there isn't access to one, another method can be used. For instance, if there are no HBOCs and drones cannot fly into a specific area, but there is a large prepared donor pool, walking blood banks should be prioritized. Moreover, drones may also take some time to deliver blood, so if a person is bleeding out quickly, HBOCs and walking blood banks would be preferred. Finally, if there is a large number of individuals requiring blood, it may be necessary to utilize all three methods.

Table 3: Evaluations of secondary solutions for blood shortages

Method	Progress	Potential Impact	Benefits	Barriers	Target Aspects
Stem cell-derived blood substitutes	Researchers are working on differentiating stem cells into red blood cells	May eliminate the need for blood transfusions	Stem cells can replicate to produce more cells	Enucleation and the production of adult hemoglobin are difficult to facilitate, and the process is slow and costly	Supply
Online awareness	Social media is increasing the number of donors	Increases blood supply	Social media can reach a large audience, including young donors	A lot of effort and time is necessary to encourage blood donors	Supply
In-person awareness	Medical offices and community events are promoting blood donations	Increases blood supply	Individuals are motivated to donate blood	Misconceptions about blood donation risks discourage donors	Supply
Autotransfusion devices	Several devices have been developed and proven to decrease the number of	Lowers the need for blood transfusions	Eliminates the need for blood type matching, shortens transfusion time, and	Some devices are expensive, blood can be contaminated, and not many people know how to	Demand, accessibility

	transfusions		reduces costs from testing, processing, and storing blood	perform autotransfusion	
Walking blood banks	The U.S. military uses walking blood banks and deems the practice safe and effective	Increases blood supply in inaccessible areas	Eliminates the need for blood banks, refrigerators, and transportation, and maintains an ideal temperature for blood	Diseases can be transmitted, rapid diagnostic testing for disease may be inaccurate, and technicians may not know how to correctly test	Supply, accessibility

8. Conclusion

There are various strategies being developed to alleviate blood shortages and deserts. The most optimal methods include hemoglobin-based oxygen carriers, hospital blood management techniques, and blood drone delivery. Hemoglobin-based oxygen carriers have the potential to replace blood transfusions. Hospital blood management policies and models promote efficient blood use and transportation. Drone delivery can bypass rough terrain and road conditions, making it faster and easier for inaccessible areas to receive blood.

Supplementary methods have less impact but still make significant contributions. Effective blood donation awareness through social media and in-person events can compel people to donate blood. Autotransfusion, in which patients' blood is collected and returned to them, minimizes the amount of blood used during surgery. Finally, walking blood banks are immediate life-saving treatments for patients who urgently need blood.

These methods are significant steps in the right direction to alleviate blood shortages. The best approach to solving blood shortages is to mainly focus on executing the primary methods and continuing to develop supplementary methods. Scientists should conduct more studies and create new technologies, and investors should fund this research. Hospital administrators should implement blood conservation strategies, global health experts should formulate safety policies, and the public should continue raising awareness and donating blood. With these efforts, the hope to solve blood shortages and blood deserts may one day turn into a reality.

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Acknowledgements

I would like to express my gratitude to my mentor, Riya Boppudi, for her generous support and guidance. I would also like to thank my peers, Aurelia Donaldson and Vanshika Jeevan for their encouragement throughout the research process. Finally, I am very grateful to my twin sister Serene Go, whose equal passion for STEM always pushes me to continue researching.

Author Biography

Arabella Go is an 11th-grade student at the Academies at Englewood in New Jersey. She has a deep passion for cardiology, hematology, and regenerative medicine, and aspires to be a cardiovascular surgeon. Arabella has been a strong advocate for blood shortages since witnessing an increase in blood crises after the COVID-19 pandemic. She earned her Girl Scout Gold Award by hosting a blood drive and raising awareness on the importance of blood donations. Compelled to address this issue further, she started investigating various ways to solve blood shortages and wrote her original review paper to propose optimal solutions.

Outside of blood shortages, Arabella loves learning medical terminology and placed in the top 5 three times in HOSA medical terminology competitions. She is also the National Chapter Director and a chapter founder for The Wishing Crane Project, a student-led non-profit organization that spreads positivity to healthcare communities. Her school chapter has donated more than 900 origami cranes and 12 gift baskets to local hospitals and hospices. In the future, she hopes to conduct further research into blood substitutes and cardiac stem cells to pave the way for better medical treatments.

Mentor Contribution Statement

Riya Boppudi advised on the abstract format, citations, and the search process for sources. She reviewed the first drafts and provided guidance on the outline and structure of the paper. All writing, literature review, and analysis were performed by the author.