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. These blood shortages are especially prominent in low- and middle-income countries and rural locations, often referred to as “blood deserts” due to the inability to easily access blood. This paper analyzes various methods to alleviate these blood shortages. Potential solutions are split into two categories: long-term and short-term solutions, and for each solution, their benefits, drawbacks, and current progress are examined. Long-term solutions that are investigated in this paper include blood substitutes, hospital blood management, and blood donation campaigns. Short-term solutions include drone delivery of blood, walking blood banks, and autotransfusion of blood. Findings indicate that these methods have been extensively developed and are very promising, and that a combined approach utilizing several of these methods is likely to be most effective. The paper recommends that further steps such as clinical trials, regulations, and technological refinements be made. Ultimately, this paper aims to increase public awareness and encourage support for the ongoing efforts to improve blood shortages.

Keywords: blood shortage, blood desert, blood transfusion, blood substitute, hospital blood management, blood donation awareness, drone delivery, blood bank, autotransfusion

1. Introduction

The need for blood is critical. Blood products are used everywhere in the field of medicine, 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). Another problem is that blood can only be used for up to 42 days, and after that it has to be thrown away (Zaleski, 2024). To make things worse, the general population, especially young donors, are unaware of the importance of blood donations or have misconceptions about donating blood (Korkut, 2023).

To alleviate and solve the issue of blood shortages, it is imperative to look at the potential strategies that scientists and researchers are developing, and in some cases, even implementing currently in order to find the best approach possible.

2. Methodology

The primary databases used to identify sources for this report were PubMed and Google Scholar. Multiple articles and websites were found on the Internet due to its vast network of resources. Sources from the Internet were published by credible authors and websites. Certain sources were obtained from the reference lists of other articles. Resources from the University of Pittsburgh's Health Science Library System were also utilized to find e-books and sources. 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*. A thorough criteria was used to evaluate whether each source should be considered for the report. The source first had to align with the purpose of the research. The source had to be written by a credible organization, journal, or author. Finally, the source had to have a recent publication date, going back no further than 2015.

After reviewing all sources, potential methods were recorded and 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 of access to blood. These approaches had different measured impacts but targeted different facets of the blood shortage issue, so the separation into two categories allowed for a fair comparison between the various solutions. Each method was analyzed based on their advantages, weaknesses, and current progress.

3. Proposed long-term methods to alleviate blood shortages

One promising solution to blood shortages is blood substitutes. One of the most favorable types of blood substitutes are hemoglobin-based oxygen carriers (HBOCs), in which hemoglobin is used to transport oxygen around the body, just like regular blood does (Sederstrom, 2025). In the U.S., the Department of Defense is funding researchers that are developing an HBOC called ErythroMer. ErythroMer is made from human hemoglobin that is encased in a phospholipid bilayer membrane to create cells (Zaleski, 2024). 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.

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. The benefits to HBOCs are that they do not carry infections, they can be used for any blood type, and they can be stored for two to five years.

Other approaches to blood substitutes include using human pluripotent stem cells (hPSCs) to make red blood cells. These stem cells are adult cells that are reprogrammed to be able to differentiate into specialized cells with specific functions. They can also replicate themselves to make more red blood cells. Scientists are researching how to take stem cells and differentiate them into red blood cells to transfuse into patients (Lee et al., 2023). The process of creating blood cells is called erythropoiesis, and the body does this in the bone marrow. During erythropoiesis, growth factors are used to push a cell through the stages of development. Similarly researchers are using growth factors to get stem cells to become red blood cells. They also put the stem cells 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 level (Twilley, 2025). With developing gene editing technologies and plans to continue testing, there is still hope for a blood substitute to be made with stem cells.

A second long-term method to take into consideration is hospital blood management. 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. In another case study in Iran, a 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 lower the number of infections, rebleeding, and cardiac incidents.

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 like desmopressin and antifibrinolytics can also be used in hospitals to reduce bleeding. 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, maintenance of centrifuges to reduce blood contamination, and continual training courses for medical staff to properly handle blood products. After intervention, researchers found that overall blood wastage rate decreased by 36.86%.

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 isn't the only option though. Apps for scheduling donations, messages on WhatsApp to donate blood, or the Facebook tool that finds local blood centers can all motivate young individuals to take action.
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, 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). Education about these health benefits and safety standards may reassure and influence the public to donate blood.

4. Proposed short-term methods to alleviate blood shortages

There are a lot of possibilities with the long-term solutions that researchers are working on. However, there is still a need to alleviate shortages right now, especially in blood deserts where rapid and accessible approaches have 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 from 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 is 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).

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℃ (Homier et al., 2020). Temperatures were able to be maintained by bags containing phase changing material. In regards 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 batteries and payload capacities. 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 long-lasting in order to increase payload and distance capabilities (Gauba et al., 2025). Another innovation that has been developed is a device called Smart Capsule that utilizes artificial intelligence 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. Both this device and the Hemafuse do not run on electricity, which make 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 literature. It also stated how 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).

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 not to use 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.

It is important to keep in mind that short-term solutions are hard to maintain and are not as efficient as long-term strategies. Therefore, these methods should not serve as alternatives to the long-term strategies, but instead be supplements to further improve blood shortages and deserts (Raykar et al., 2024).

5. Discussion

The long-term and short-term solutions mentioned in this paper are monumental strides on the path to solving blood shortages. The research and progress that has 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 with costs, accessibility, safety, and other factors taken into consideration. It may also be a challenge for hospitals to set up blood inventory management systems with the immense amount of time and effort it will take.

Safety concerns are a huge issue for autotransfusion and walking blood banks. The risks of blood contamination and disease transmission need to be addressed. Furthermore, substantial costs hinder the development of drones for blood delivery and autotransfusion devices. Plans to tackle

these aspects should be formulated and implemented so that these methods can be put into practice.

Technological advancements and further research on blood substitutes, blood delivery drones, and autotransfusion devices will refine these methods. New ideas for hospital blood management and blood donation awareness efforts, such as artificial intelligence use, inventory programming models, initiatives, and techniques utilizing social media will further assist with improving these solutions.

After reviewing all of the potential long-term and short-term solutions, this paper finds that an approach utilizing a combination of solutions will be the most effective at alleviating blood shortages. These methods target different components that contribute to blood shortages, so by addressing multiple aspects, blood shortages can be solved efficiently. Further discussions, research, and technological improvements to these methods are recommended to continue ongoing efforts.

6. Conclusion

There are various short-term and long-term strategies that are being developed to alleviate blood shortages and deserts. Blood substitutes like hemoglobin-based oxygen carriers and red blood cells derived from stem cells have the potential to replace blood transfusions. Hospital blood management techniques, like reducing the amount of elective surgeries and unnecessary

transfusions, are also able to promote efficient blood use. Effective blood donation awareness including using social media and holding community events can compel people to donate blood.

Blood deserts can be improved by transporting blood with drones, which is much faster than ambulances that have to travel through rough terrain and poor road conditions. Autotransfusion during surgery, in which patients' blood is collected and returned to them, can minimize the amount of blood used. Finally, walking blood banks can be an immediate life-saving treatment for patients who urgently need blood.

These methods are significant steps in the right direction to alleviate blood shortages. Although there are concerns and obstacles that need to be addressed, with continued efforts, technological advancements, and further discussions, the hope to solve blood shortages and blood deserts may one day turn into a reality.

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EDITOR COMMENTS AND RECOMMENDATION

Both reviewers agreed that the paper is very well researched and written, with robust utilization of the existing literature focused on a pressing health problem. To strengthen the manuscript and enhance its rigor, the reviewers have provided guidance in several areas, and both emphasize a focus on revision of the methodology section to elevate the scholarly impact of this manuscript. Given the reviewer feedback, the editor's recommendation is to accept the manuscript following major revisions.

Reviewer 1

This is a nicely researched and well-structured paper that tackles a critical, real-world public health challenge. The author demonstrates a strong command of the literature, synthesizing a wide range of recent and relevant sources from academic journals, reputable news outlets, and organizational reports. The categorization of solutions into long-term and short-term strategies is logical and provides a clear framework for the discussion. The writing is clear, professional, and accessible. This paper has significant potential to inform and raise awareness about a vital issue. The revisions suggested below are aimed at elevating the work from a comprehensive literature review to a more analytically rigorous and formally polished scholarly article.

Strengths:
Engagement with Literature: The paper's greatest strength is its breadth and depth of research. The author has gone beyond surface-level reporting to engage with technical details of blood substitutes, logistical models, and clinical studies, citing them appropriately.

Clarity & Structure: The paper follows a standard scientific format effectively. The introduction sets a compelling context, the methodology is transparent, and the solutions are presented in a logical, easy-to-follow manner. The conclusion effectively summarizes the key points.

Originality & Significance: While the topic of blood shortages is well-known, the paper's organized synthesis of cutting-edge technological, logistical, and social solutions in one place is a valuable contribution. The focus on "blood deserts" is particularly timely and important.

Areas for Major Revisions:

1. Strengthen the Analytical "So What?" in the Discussion:

The current Discussion section effectively lists concerns but doesn't fully synthesize the information to build a unique argument or set of prioritized recommendations. It concludes that a "combined approach" is best, which is sensible but could be more insightful.

To add rigor and originality, restructure the Discussion to move from description to analysis. For example, you could create a comparative table or a paragraph that evaluates each solution against key criteria: Feasibility (cost, infrastructure), Timeline (short vs. long-term), Scale of Impact (local vs. global), and Primary Barrier (technology, regulation, public acceptance). Then, based on this analysis, propose a tiered strategy. For instance: "For immediate crisis response in blood deserts, drone delivery paired with walking blood banks (where legally and ethically permissible) is most critical. For sustainable systemic change, investment in HBOC clinical trials must be paired with national campaigns to overhaul hospital inventory management and donor recruitment." This transforms your excellent summary into a proactive, evidence-based policy brief.

2. Refine the Methodology Section for Scholarly Precision:

The methodology is clear but could be enhanced to meet formal academic standards. Phrases like "sources from the Internet" and "a thorough criteria" are vague.
To enhance clarity, please specify:

* The exact date range of your search (e.g., "2015 to present").
* How you determined source credibility (e.g., "Sources were limited to peer-reviewed journals, official reports from entities like the WHO or Red Cross, and news articles from reputable outlets like NPR, Science, and The Lancet.").
* How you arrived at the long-term/short-term categorization. Was this an observation from the literature, or a framework you imposed? Briefly explaining this analytical choice
strengthens your method.
* Revise the language to be more precise: e.g., "A set of inclusion criteria was used..." instead of "a thorough criteria."

3. Address Formatting and Stylistic Refinements:
The manuscript requires careful formatting to adhere to the journal's style guide before it can be published.

Line Numbers: Add continuous line numbers in the left margin as required. Font & Spacing: Change the font to Lora and line spacing to 1.15.

APA Style: Take a meticulous look at the Reference list for full APA 7th edition compliance. I noticed a few inconsistencies (e.g., some URLs are not hyperlinked consistently, some journal titles are not fully italicized). The in-text citations are generally good, but ensure every citation in the text has a corresponding entry in the reference list, and vice-versa.

Abstract: Consider slightly refining the abstract to more explicitly state your paper's conclusion or primary finding (e.g., "This analysis concludes that while technological

innovations like blood substitutes and drones are promising, a multi-pronged strategy addressing supply, demand, and distribution is essential.").

4. Deepen the "Conclusion" to Match the Paper's Scope:
The conclusion nicely recaps the solutions but ends on a general note of hope. Given the strong analysis in the body, the conclusion can be more powerful.
Use the conclusion to briefly reiterate your most critical finding from the revised Discussion. End with a specific "call to action" for different stakeholders (e.g., researchers, policymakers, hospital administrators, the public) based on the solutions you've outlined. This creates a more impactful and empowering finish.

This is a good paper that reflects tremendous effort, intellectual curiosity, and a passion for solving humanitarian problems. You have all the core components of an outstanding literature review. The major revisions suggested here are primarily structural and analytical—they are about refining and framing your excellent research to maximize its scholarly impact and adhere to publication standards. The next step is to hone the skill of synthesizing it into a unique, argument-driven contribution.

Reviewer 2

Originality & Significance
This paper tackles a highly topical and important area of research on strategies to alleviate blood shortages and blood deserts. The student does well to identify this area for further research, and equally, the literature review is ambitious to cover many different challenges associated with blood donations. Overall, a key strength of the paper is that it has the potential to significantly contribute to an important area of research.

The paper's unique contribution is however unclear. There have been recently published reviews covering this topic, and the paper would have been strengthened further if it had expanded upon previous work. In these cases, it is often better to narrow onto one solution (e.g., blood-delivery with drones). By focussing on one potential solution, the student can explore a singular issue deeply to further contribute. Alternatively, the paper can maintain its breadth and contribute further by recommending which solutions should be more readily prioritised for adoption or research with argued justifications. This will require more engagement with the literature. Ultimately, the breadth (and ambition) of the student's work does constrain the paper's ability to dive deeper to contribute more unique ideas. As a recommendation, deeper insights that promote originality and significance should be prioritised over breadth.

Clarity
Overall, the clarity of the paper is good and well-written. The paper was easy to read as simple language was used without overly complex words. To improve the clarity further,

I encourage the student to be more concise to achieve a more scientific style of writing. Ideas should be communicated with the least words while maintaining simple yet scientific-style writing (this will come with practice!). For example:

Original: “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).”

Modification: “Low- and middle-income countries face an annual shortage of 102 million units of blood, with shortages widespread across sub-Saharan Africa and south Asia (Raykar et al., 2024).”

Structure

The paper separates short-term and long-term methods. The paper justifies this as long-term methods focus on lack of blood supply vs short-term strategies on blood access. This way of structuring the paper can appear confusing to the reader at face-value, as it also implicitly implies that each strategy may have a short-term or long-term effect or implementation times. Furthermore, it is not clear, for example, why hospital management systems (models to determine time-saving and cost-efficient routes for blood donations) are considered long-term but drone-delivery short-term. The structuring of the paper’s strategies into short-term and long-term did not feel appropriate or relevant to the paper’s goal. Instead, the structuring should be to be clear and explicit. For example, having separate sections for:

(1) Blood substitutes
- hemoglobin-based oxygen
- human pluripotent stem cells

(2) Hospital blood management
- Models for blood inventory management
- Models for time-saving and cost-efficient routes when transporting blood
- Iran case-study: sending surplus blood from hospitals to other blood centres (reducing blood wastage)

(3) Promoting blood donations
- Community events and organisation partnerships
- Social media
- Education on blood donations

(4) Blood accessibility
- Drone-delivery
- Autotransfusion
- Blood banks

This structure explicitly and clearly separates all the different methods of alleviating both blood supply and accessibility without categorising them into “long-term” or “short-term” headings which may introduce confusion.

Use of Evidence & Research Methods
The paper is well-cited and has a references list to accommodate the citations. The student does a very good job in producing a well-conducted synthesises of the available studies. Plenty of breadth is shown, covering many different topics. Furthermore, relevant statistics from previous studies are sometimes used effectively to back up their claims. This should however be maintained throughout the paper.

The key area of improvement is the methodology section. It is good to see that the student aimed to identify good-quality studies in their review. This adds to the robustness of their paper. However, this section should be improved upon further. It is stated that “thorough criteria” was used, defined by including credible organisations, journals or authors in the review. This criterion is not elaborated on. “Credible” is open to interpretation - without an explicit definition it raises concerns that study inclusion was influenced by bias. Details on which papers were excluded (if documented) would be helpful or defining an explicit inclusion criterion would alleviate these concerns. Finally, the methods section is clear overall, but small phrasing issues are present. The methods section should describe what you did rather than discuss the output/results of the literature search. For example, “Certain sources were obtained from the reference lists of other articles” is a result of your literature search. This should be phrased as: “The reference lists of the studies included were also reviewed to identify additional relevant papers.” – this is what you did from a methodology perspective.

Engagement with Literature
The papers key strength is that it effectively synthesised and understands the available studies on blood strategies. The breadth is large, but this sometimes leaves less room for engaging more deeply. For example, it is mentioned that COVID-19 pandemic forced many hospitals to adopt blood management strategies e.g., “It is also beneficial to use a hemoglobin trigger of 7g/dL or lower in nonbleeding patients” – the immediate afterthoughts are what are the drawbacks of having a lower trigger threshold? Are there negative consequences? Could the negative consequences outweigh the benefits in this case? These questions explore further and identify which strategies are most effective. This should be followed by well-argued policy recommendations and priorities across the strategies. For example, given the advantages and limitations, should lower hemoglobin thresholds be considered as a worst-case intervention compared to other possible methods? Altogether, additional analysis of the literature and policy recommendations would greatly strengthen the content.

Grammar and language
Overall good. Please see my comments under “clarity” where I recommend improvements to conciseness.

Final recommendation: Revise and Submit

This paper has clear strengths, including a topical and highly relevant research area. Furthermore, the paper covers plenty of breadth and shows good understanding of the literature. Well done!

Major revisions focused on improving the paper's originality, significance and engagement with the literature will push to publication level. Given the required revisions, a revise and submit is appropriate.

The following should be revised:

1.) Additional engagement of the literature. More focus on the advantages and limitations of each strategy and tying this to final policy recommendations (with clear priorities of these recommendations) – policy recommendations can be considered as a separate section or ingrained within the existing content. This will improve the paper's originality, significance, and engagement with the literature.

2.) Modifications to the current structuring (see my comments under "structure")

3.) Methodology section (see my comments under "Use of Evidence & Research Methods")

Methods to Alleviate Blood Shortages and Blood Deserts

[Name redacted]
[School redacted]

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 desert, blood transfusion, blood substitute, hospital blood management, blood donation awareness, drone delivery, blood bank, autotransfusion

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 of blood is also another contributor to the limited supply (Zaleski, 2024). To make things worse, the general population, especially young donors, are unaware of the importance of blood donations or have 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 report 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 was 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, and Science. Finally, the source had to be published between 2015 and 2025.

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 entirely. One of the most favorable types of blood substitutes are 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 that 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).

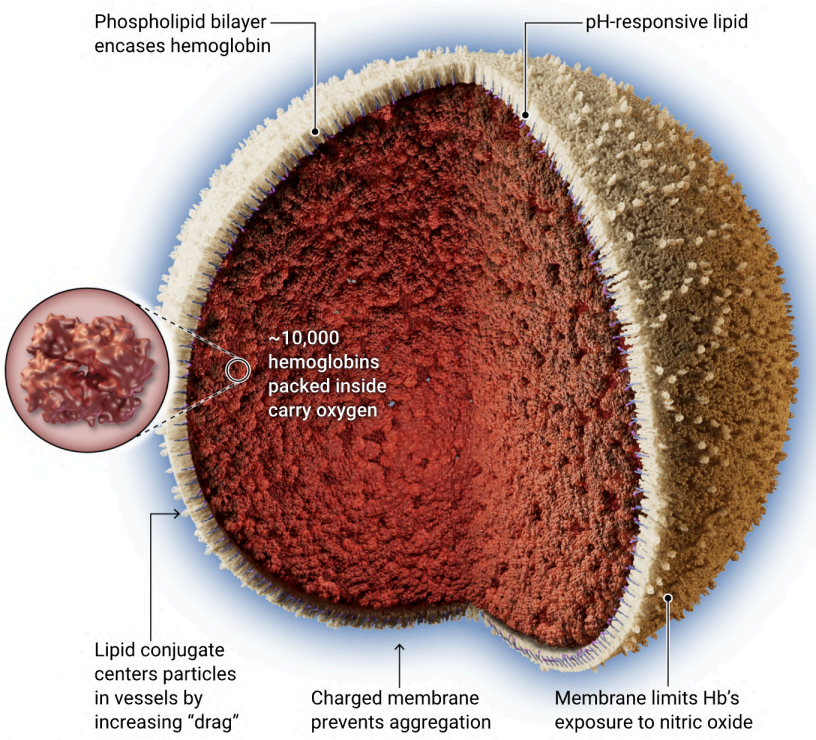

Figure 1: Diagram of an ErythroMer cell showing the lipid membrane surrounding the hemoglobins (Zaleski, 2024)

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 level (Twilley, 2025). With developing gene editing technologies and plans to continue testing, there is still hope for a blood substitute to be made with stem cells.

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 lower the number of infections, rebleeding, and cardiac incidents. This lower hemoglobin trigger does not have critical consequences on 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, maintenance of centrifuges to reduce blood contamination, and continual training courses for medical staff to properly handle blood products. After intervention, researchers found that overall blood wastage rate decreased by 36.86%.

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 isn't 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 health benefits of blood donations and safety standards may reassure and 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).

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 from 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 is 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℃ (Homier et al., 2020). Temperatures were able to be maintained by bags containing phase changing material. In regards 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 long-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. Both this device and the Hemafuse do not run on electricity, which make 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).

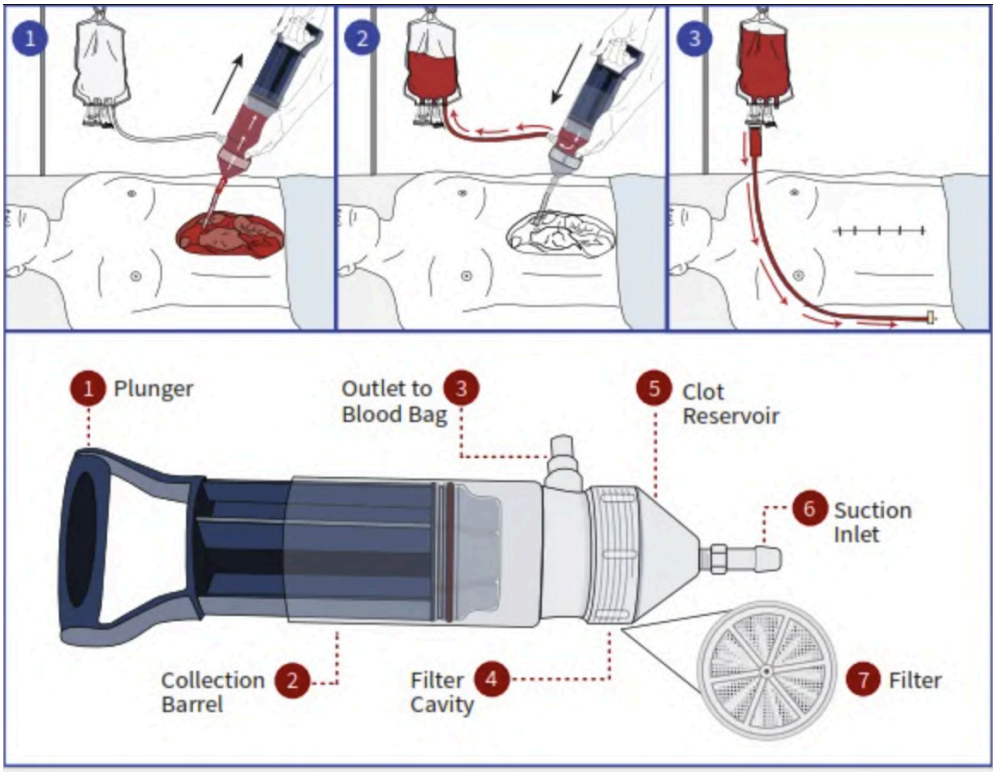

Figure 3: Depiction of the Hemafuse autotransfusion device's components and steps for utilization (Hansman, 2015)

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 literature. It also stated how 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).

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 not to use 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.

It is important to keep in mind 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 has 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 with 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 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 its 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 needs 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.

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

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 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, suggests the best time-saving and cost-efficient blood transportation routes	Can be improved more with new models and machine learning	Demand, accessibility

Hospital blood management policies	Hospitals have implemented policies and saw effective results	Cuts down blood wastage	Lowers the amount of infections, rebleeding, and cardiac incidents	Takes time and discussion for hospitals to implement policies	Demand
Blood drone delivery	Countries like Rwanda and Ghana have seen success with drone delivery	Reduces transportation time and number of expired blood products	Bypasses rough terrain, can fly autonomously, 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 the 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.

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 been proven to decrease the number of transfusions	Lowers the need for blood transfusions	Eliminates the need for blood type matching, shortens transfusion time, and reduces costs from testing, processing, and storing blood	Some devices are expensive, blood can be contaminated, and not many people know how to perform autotransfusion	Demand, accessibility

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 continue developing 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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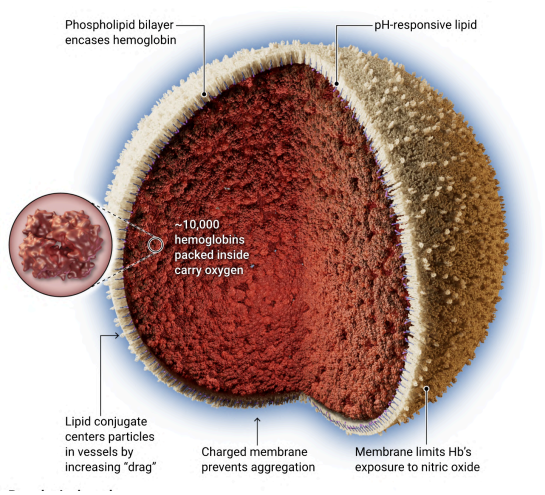
LINE NUMBERS	ORIGINAL	CHANGE
1-3	Separate title page	Removed title page; title is above beginning of text
Whole manuscript	Times New Roman font, double spacing, and no line numbers	Font changed to Lora, spacing changed to 1.15, and line numbers added
10-12	These blood shortages are especially prominent in low- and middle-income countries and rural locations, often referred to as “blood deserts” due to the inability to easily access blood.	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.
12	This paper analyzes various methods to alleviate these blood shortages.	This paper analyzes various methods to alleviate these issues.
13-19	Potential solutions are split into two categories: long-term and short-term solutions, and for each solution, their benefits, drawbacks, and current progress are examined. Long-term solutions that are investigated in this paper include blood substitutes, hospital blood management, and blood donation campaigns. Short-term solutions include drone delivery of blood, walking blood banks, and autotransfusion of blood.	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.

19-25	Findings indicate that these methods have been extensively developed and are very promising, and that a combined approach utilizing several of these methods is likely to be most effective.	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.
25-27	The paper recommends that further steps including clinical trials, regulations, and technological refinements be made.	The paper recommends that further steps including clinical trials, regulations, increased funding, and technological refinements be made.
27-28	Ultimately, this paper aims to increase public awareness and encourage support for the ongoing efforts to improve blood shortages.	Ultimately, this paper aims to increase awareness and support for the efforts to improve blood shortages.
36-37	Blood products are used everywhere in the field of medicine, including surgeries, treatments for diseases, and emergencies.	Blood products are used everywhere in the medical field, including surgeries, treatments for diseases, and emergencies.
49-50	Another problem is that blood can only be used for up to 42 days, and after that it has to be thrown away (Zaleski, 2024).	The 42-day shelf of blood is also another contributor to the limited supply (Zaleski, 2024).

55-58	To alleviate and solve the issue of blood shortages, it is imperative to look at the potential strategies that scientists and researchers are developing, and in some cases, even implementing currently in order to find the best approach possible.	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.
63-64	Multiple news articles and websites were found on the Internet due to its vast network of resources.	The search engines Google and Safari were also utilized to find news articles and websites due to the web's vast network of resources.
64	Sources from the Internet were published by credible authors and websites.	(Deleted)
64-65	Certain sources were obtained from the reference lists of other articles.	The reference lists of included sources were examined to select additional papers.
66-67	Resources from the University of Pittsburgh's Health Science Library System were also utilized to find e-books and sources.	Search engines and catalogs from the University of Pittsburgh's Health Science Library System were also utilized to find e-books and journals.
74-76	A thorough criteria was used to evaluate whether each source should be considered for the report.	The following inclusion criteria was used to evaluate whether each source should be considered for the report.
76	The source first had to align with the purpose of the research.	First, the source had to align with the purpose of the research.
76-78	The source had to be written by a credible organization, journal, or	The source needed to be a peer-reviewed paper or article from

	author.	a reputable organization, such as the American Red Cross, NPR, Smithsonian Magazine, and Science.
78-79	Finally, the source had to have a recent publication date, going back no further than 2015.	Finally, the source had to be published between 2015 and 2025.
81-87	After reviewing all sources, potential methods were recorded and 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 of access to blood.	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.
87-90	(Added in)	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.
90-93	These approaches had different measured impacts but targeted	Each method was analyzed on their advantages, weaknesses, and

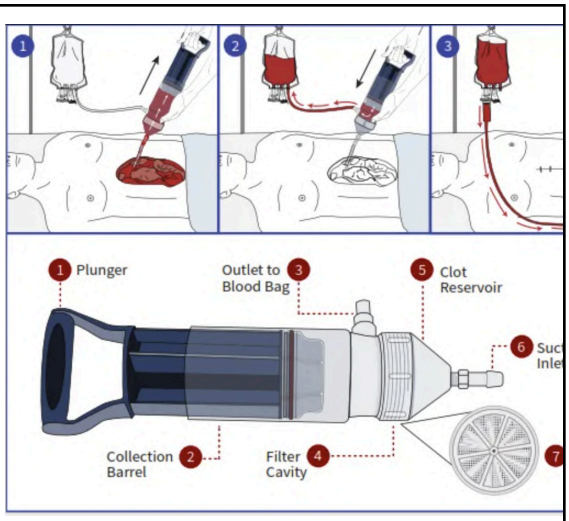
	different facets of the blood shortage issue, so the separation into two categories allowed for a fair comparison between the various solutions. Each method was analyzed based on their advantages, weaknesses, and current progress.	current progress. Based on this information, the most promising solutions were identified and recommendations were developed.
95	Proposed long-term methods to alleviate blood shortages	Blood Substitutes
97-98	One promising solution to blood shortages is blood substitutes.	A very promising solution to blood shortages is blood substitutes, because it eliminates the need for human blood entirely.
101-102	(Added in)	HBOCs do not carry infections, can be used for any blood type, and can be stored for two to five years.
103-105	ErythroMer is made from human hemoglobin that is encased in a phospholipid bilayer membrane to create cells (Zaleski, 2024).	ErythroMer is made from recycled human hemoglobin taken from expired blood, which is encased in a phospholipid bilayer membrane to create cells ("ErythroMer," 2025).
112-114	Preclinical testing on animals has been successful so far, and researchers are working towards human clinical trials.	Preclinical testing on animals has been successful so far, and researchers are working towards human clinical trials (Zaleski, 2024).

116-118	(Added in)	 Figure 1: Diagram of an ErythroMer cell showing the lipid membrane surrounding the hemoglobins (Zaleski, 2024)
129	The benefits to HBOCs are that they do not carry infections, they can be used for any blood type, and they can be stored for two to five years.	(Deleted)
132-133	These stem cells are adult cells that are reprogrammed to be able to differentiate into specialized cells with specific functions.	These stem cells are reprogrammed adult cells that can differentiate into specialized cells with specific functions.
134-136	Scientists are researching how to take stem cells and differentiate them into red blood cells to transfuse into patients (Lee et al., 2023).	Scientists are researching how to differentiate stem cells into red blood cells to transfuse into patients (Lee et al., 2023).
136-138	The process of creating blood cells is called erythropoiesis, and the body does this in the bone marrow. During erythropoiesis, growth	The process of creating blood cells, called erythropoiesis, is done in the bone marrow. During erythropoiesis, growth factors push

	factors are used to push a cell through the stages of development.	a cell through the stages of development.
138-140	Similarly researchers are using growth factors to get stem cells to become red blood cells. They also put the stem cells in environments that mimic human body conditions.	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.
155	(Added in)	Hospital Blood Management
157-158	A second long-term method to take into consideration is hospital blood management.	Hospital blood management targets a different facet of blood shortages: demand for blood.
164-166	In another case study in Iran, a flexible robust mathematical model was created to find solutions to issues in the blood supply chain (Khalilpourazari & Hashemi Doulabi, 2022).	Another flexible robust mathematical model was created to find solutions to issues in the blood supply chain (Khalilpourazari & Hashemi Doulabi, 2022).
183-187		This lower hemoglobin trigger does not have critical consequences on 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).
191-195	Pharmaceutical products like desmopressin and antifibrinolytics can also be used in hospitals to reduce bleeding.	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).
212	(Added in)	Blood Donation Awareness
222-225	Apps for scheduling donations, messages on WhatsApp to donate blood, or the Facebook tool that finds local blood centers can all motivate young individuals to take action.	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%.
235-242	In addition, 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). Education about these health benefits and safety standards may reassure and influence the public to donate blood.	In addition, education about health benefits of blood donations and safety standards may reassure and 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).
244	Proposed short-term methods to alleviate blood shortages	Blood Accessibility

246-247	There are a lot of possibilities with the long-term solutions that researchers are working on. However, there is still a need to alleviate shortages right now, especially in blood deserts where rapid and accessible approaches have to be utilized.	Blood accessibility solutions are extremely beneficial to blood deserts, which require rapid and accessible approaches to be utilized.
273-274	(Added in)	 Figure 2: Zipline drone delivering a blood product (Levy, 2022)
287-288	Researchers are looking to make improvements in drone technology, including better batteries and payload capacities.	Researchers are looking to make improvements in drone technology, including better payload capacities, batteries, and temperature regulation.
292-294	Another innovation that has been developed is a device called Smart Capsule that utilizes artificial intelligence to monitor and regulate temperatures (Liu et al., 2022).	A device called Smart Capsule that utilizes artificial intelligence has been developed to monitor and regulate temperatures (Liu et al., 2022).

334-336	(Added in)	 Figure 3: Depiction of the Hemafuse autotransfusion device's components and steps for utilization (Hansman, 2015)
382-387	It is important to keep in mind that short-term solutions are hard to maintain and are not as efficient as long-term strategies. Therefore, these methods should not serve as alternatives to the long-term strategies, but instead be supplements to further improve blood shortages and deserts (Raykar et al., 2024).	It is important to keep in mind 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).
391-392	The long-term and short-term solutions mentioned in this paper are monumental strides on the path to solving blood shortages.	The solutions mentioned in this paper are monumental strides on the path to solving blood shortages.
398-402	It may also be a challenge for hospitals to set up blood inventory	Blood management models using machine learning should be

	management systems with the immense amount of time and effort it will take.	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.
402-407	(Added in)	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 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.
409-413	Safety concerns are a huge issue for autotransfusion and walking blood banks. The risks of blood contamination and disease transmission need to be addressed.	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 its safety. Distributing guidelines and resources on how to operate

		autotransfusion devices will allow for safe and widespread use.
414-416	Furthermore, substantial costs hinder the development of drones for blood delivery and autotransfusion devices. Plans to tackle these aspects should be formulated and implemented so that these methods can be put into practice.	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.
418-424	Technological advancements and further research on blood substitutes, blood delivery drones, and autotransfusion devices will refine these methods. New ideas for hospital blood management and blood donation awareness efforts, such as artificial intelligence use, inventory programming models, initiatives, and techniques utilizing social media will further assist with improving these solutions.	Lastly, studies and technological advancements will benefit all solutions mentioned in the paper. Enucleation and adult hemoglobin production needs 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.
426	(Added in)	Table 1: Recommendations for blood shortage solutions (Table 1 is below)
428-431	After reviewing all of the potential long-term and short-term solutions, this paper finds that an approach utilizing a combination of solutions	After reviewing all of the potential solutions, this paper finds that hemoglobin-based oxygen carriers, computational blood management

	will be the most effective at alleviating blood shortages.	models, hospital blood management policies, and blood drone delivery will be most effective at alleviating blood shortages.
431-435	(Added in)	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.
437	(Added in)	Table 2: Evaluations of primary solutions for blood shortages (Table 2 is below)
439-442	(Added in)	Hemoglobin-based oxygen carriers are the 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.
442-445	(Added in)	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.
445-448	(Added in)	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.
450-454	These methods target different components that contribute to blood shortages, so by addressing multiple aspects, blood shortages can be solved efficiently.	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.
454-455	Further discussions, research, and technological improvements to these methods are recommended to continue ongoing efforts.	Table 3 evaluates the supplementary strategies against the key criteria used in Table 2 for comparison.
457	(Added in)	Table 3: Evaluations of secondary solutions for blood shortages (Table 3 is below)
461-463	There are various short-term and long-term strategies that are being developed to alleviate blood shortages and deserts.	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.
464-465	Blood substitutes like hemoglobin-based oxygen carriers and red blood cells derived from stem cells have the potential to replace blood transfusions.	Hemoglobin-based oxygen carriers have the potential to replace blood transfusions.
465-466	Hospital blood management techniques, like reducing the amount of elective surgeries and unnecessary transfusions, are able to promote efficient blood use.	Hospital blood management policies and models promote efficient blood use and transportation.
466-467	Effective blood donation awareness including using social media and holding community events can compel people to donate blood.	Drone delivery can bypass rough terrain and road conditions, making it faster and easier for inaccessible areas to receive blood.
469-471	Blood deserts can be improved by transporting blood with drones, which is much faster than ambulances that have to travel through rough terrain and poor road conditions.	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.
471-473	Autotransfusion during surgery, in which patients' blood is collected and returned to them, can minimize the amount of blood used.	Autotransfusion, in which patients' blood is collected and returned to them, minimizes the amount of blood used during surgery.
473-474	Finally, walking blood banks can be an immediate life-saving treatment for patients who urgently need blood.	Finally, walking blood banks are immediate life-saving treatments for patients who urgently need blood.

477-482	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 continue developing 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.
482-484	Although there are concerns and obstacles that need to be addressed, with continued efforts, technological advancements, and further discussions, the hope to solve blood shortages and blood deserts may one day turn into a reality.	With these efforts, the hope to solve blood shortages and blood deserts may one day turn into a reality.
504-505	Here are 3 solutions to get blood to folks in 'blood deserts.' one is often illegal.	*Here are 3 solutions to get blood to folks in 'blood deserts.' One is often illegal.*
528	https://kalocyte.com/erythromer/	https://kalocyte.com/erythromer
548-549	https://smithsonianmag.com/innovation/pump-could-make-blood-transfusions-safer-and-cheaper-developing-world-180957250/	https://smithsonianmag.com/innovation/pump-could-make-blood-transfusions-safer-and-cheaper-developing-world-180957250
582-583	https://www.wired.com/story/drones-have-transformed-blood-deliver	https://www.wired.com/story/drones-have-transformed-blood-deliver

	y-in-rwanda/	y-in-rwanda
590-595	(Added in)	Myles, P. S., Smith, J. A., Forbes, A., Silbert, B., Jayarajah, M., Painter, T., Cooper, D. J., Marasco, S., McNeil, J., Bussières, J. S., McGuinness, S., Byrne, K., Chan, M. T., Landoni, G., Wallace, S., & ATACAS Investigators of the ANZCA Clinical Trials Network (2017). Tranexamic Acid in Patients Undergoing Coronary-Artery Surgery. *The New England Journal of Medicine*, 376(2), 136–148. https://doi.org/10.1056/NEJMoa1606424
608-614	(Added in)	Palmieri, T. L., Holmes, J. H., 4th, Arnoldo, B., Peck, M., Potenza, B., Cochran, A., King, B. T., Dominic, W., Cartotto, R., Bhavsar, D., Kemalyan, N., Tredget, E., Stapelberg, F., Mozingo, D., Friedman, B., Greenhalgh, D. G., Taylor, S. L., & Pollock, B. H. (2017). Transfusion Requirement in Burn Care Evaluation (TRIBE): A Multicenter Randomized Prospective Trial of Blood Transfusion in Major Burn Injury. *Annals of Surgery*, 266(4), 595–602. https://doi.org/10.1097/SLA.0000000000002408
683	https://www.zipline.com/	https://www.zipline.com

Dear reviewer,

Thank you so much for your feedback on my paper, *Methods to Alleviate Blood Shortages and Blood Deserts*. I found your comments and recommendations very insightful, and they have greatly improved my writing. Below are point-by-point replies to each of your suggestions.

1. Strengthening Discussion Section
    - Removed the term “combined approach” and replaced it with four specific optimal solutions (hemoglobin-based oxygen carriers, computational models, blood management policies, and drone delivery)
    - Stated that secondary solutions were not as optimal as primary solutions, but could supplement blood shortage alleviation efforts
    - Created Table 1 to highlight recommendations for each solution
    - Utilizing some of the criteria you suggested, I created Table 2 to evaluate the primary solutions and Table 3 to evaluate the secondary solutions

2. Methodology Section
    - Replaced vague words (“sources from the internet, “thorough criteria”) with specific criteria that I used
    - Included a date range and accepted your suggestion of source credibility
    - Explained how I categorized solutions into long-term and short-term, but ultimately created entirely new categories (blood substitutes, blood management, donation awareness, accessibility) with explanations on why

3. Formatting Requirements
    - Changed font size and line spacing and added line numbers
    - Fixed URL hyperlinks, italicized journal titles, made sure that every in text citation had an entry in the reference list
    - Included my specific finding on primary and secondary solutions in the abstract

4. Deepening Conclusion Section
    - Summarized my findings on primary and secondary solutions mentioned in discussion
    - Included a call to action to multiple parties such as researchers, policy makers, and investors

Once again, thank you so much for your comments and suggestions. I appreciate your time and consideration.

Sincerely,
[Name redacted]

Dear reviewer,

Thank you so much for your feedback on my paper, *Methods to Alleviate Blood Shortages and Blood Deserts*. I found your comments and recommendations very insightful, and they have greatly improved my writing. Below are point-by-point replies to each of your suggestions.

1. Originality
    - Included specific findings on the most optimal primary solutions (hemoglobin-based oxygen carriers, computational models, blood management policies, and drone delivery)
    - Stated that secondary solutions were not as optimal as primary solutions, but could supplement blood shortage alleviation efforts
    - Created Table 1 to highlight recommendations for each solution
    - Created Table 2 to evaluate the primary solutions and Table 3 to evaluate the secondary solutions

2. Clarity
    - Replaced vague terms (“sources from the internet, “combined approach”) with specific explanations
    - Improved clarity in multiple sections by cutting down unnecessary words

3. Structure
    - Explained how I initially categorized solutions into long-term and short-term
    - Ultimately created entirely new categories (blood substitutes, blood management, donation awareness, accessibility) with explanations on why

4. Evidence and Methods
    - Utilized new sources and statistics, as well as images
    - Replaced words like “thorough criteria” and “credible” with specific criteria I used to select sources
    - Did not record which articles I excluded from paper, so I could not detail them in the methodology section
    - Fixed phrasing from describing results to describing processes

5. Engagement with Literature
    - I found that hemoglobin triggers of 7g/dL do not have critical consequences on patients, and included evidence to back this up

Once again, thank you so much for your comments and suggestions. I appreciate your time and consideration.

Sincerely,
[Name redacted]

Post-review critical

You've tackled a complex, real-world problem and presented a range of thoughtful solutions in a structured way. Your writing is clear, your sources are relevant and recent, and your use of tables to summarize information is effective. This is strong work that shows a lot of effort and understanding.

To make it even stronger, here are some constructive suggestions for deepening your analysis and sharpening your argument.

1. Add More Analysis—Not Just Description
Right now, your paper does a great job of describing each solution. The next step is to **analyze** them more deeply. For each of the four main sections (3–6), try adding a short paragraph that answers questions like:
- Who benefits most?
- What's the biggest hurdle? (e.g., Is it cost? Safety? Public trust? etc)
- How could this work in the real world? (e.g., What would it take to get hospitals to use HBOCs? etc)

This will help you move from reporting facts to showing your own critical thinking.

2. Connect the Solutions
You present four separate categories, but in reality, these solutions could work together—or sometimes conflict. For example:
- If HBOCs becomes widely available, would people still donate real blood?
- Could drones and walking blood banks be used in the same region during a disaster?

Adding a paragraph in your Discussion about how these ideas relate to each other would make your paper feel more complete and realistic.

3. Go Deeper on Drawbacks
You mention drawbacks briefly, but don't shy away from exploring them further. For instance:
- HBOCs: Earlier versions failed because they raised blood pressure. What's different about the new ones like ErythroMer? Is it truly different or even better?
- Walking blood banks: The WHO strongly advises against them. Under what extreme circumstances might they be worth the risk? What safeguards would be needed?

Showing you've thought through the problems will make your recommendations more convincing.

4. Strengthen Your Methodology Section
For a high school paper, your methods are clear. To make it stronger, you could:
- State what type of review you did (e.g., "narrative review" or "structured survey of recent literature").

- Briefly mention any limitations—like maybe most studies you found were from the U.S., which might not apply everywhere.

5. Make Your Conclusion More Forward-Looking
Your conclusion summarizes well. To give it more impact, try ending with:
- A specific call to action: “Researchers should focus on _____ next.”
- A policy idea: “Governments could fund _____ to make drones more affordable.”
- A final thought: Why should people care about this issue now?

6. Small Presentation Tweaks
- Cite your figures in the text: Right before or after Figure 1, briefly say what it shows and why it matters.
- Check your phrasing: Instead of “This will solve the problem,” try “This could help reduce the problem,” since most solutions are still in progress.
- Read it aloud: This helps catch awkward sentences and improve flow.

You’ve done the hard part—gathering great information and organizing it clearly. Now, by adding your own analysis and connections, you’ll make this paper not just informative, but insightful.

Final decision for Methods to Alleviate Blood Shortages and Blood Deserts

Decision: *Accept with minor revisions*

The paper is worthy of publication. The student made great improvements based on my comments. The methods and structure have been substantially strengthened making for a more coherent paper. Some improvements have been made on the critical engagement, presenting Tables 1-2 to support their recommendations. While critical engagement could still be improved, additional work would push beyond the scope of a student paper given the existing breadth and immense effort. I recommend for the student's future endeavours to prioritise quality over breadth to develop more critical insights. Well done!

Minor revision: Please fix lines 276-287 (below Figure 2). It should be font Lora (currently Nova Mono).