

# From Murder to Miracles: The Basic Principles of Autologous Cell Salvage and the Bloody History That Led Us Here



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## INTRAOPERATIVE CELL SALVAGE

Intraoperative cell salvage has become a cornerstone of contemporary surgical practice, significantly contributing to blood conservation and optimizing patient outcomes. The evolution of this technology is intricately connected with the historical challenges and advancements in blood transfusion practices over the centuries. This article examines the historical evolution of blood transfusion, elucidates the fundamental principles underlying cell salvage, and discusses its current applications in both intraoperative and postoperative settings. In understanding the historical trajectory of blood transfusion and cell salvage, we can better appreciate the advancements that have shaped modern surgical practices and continue to inform future innovations.

## FUNDAMENTAL PRINCIPLES

### Collection and Anticoagulation

Blood collection during surgery is achieved through specialized suction tubing, designed to integrate

anticoagulants at the point of collection, channeling the blood into a filtered collection reservoir or cardiotomy reservoir. Given that excessive turbulence from high vacuum pressures can result in erythrocyte destruction, it is critical to apply the lowest suction pressure acceptable to the surgical procedure, typically regulated to 160 mm Hg or less. Using the largest available suction tip is advisable to optimize the collection of pooled blood while minimizing damage to red blood cells. To prevent hemolysis, skimming or suctioning at the blood-air interface should be avoided. Soaked lap sponges, which can retain up to 100 mL of blood, should be rinsed in isotonic solution, wrung out, and the resulting blood-tinged solution should be collected via suction into the cardiotomy reservoir.

The anticoagulant-to-blood ratio must be meticulously titrated, typically to 15 mL of anticoagulant per 100 mL of blood. It is prudent to err on the side of administering excess anticoagulant, as insufficient anticoagulation can lead to clot formation, whereas higher doses pose no significant clinical risk (Waters, 2005). Standard practice involves using 30,000 units of heparin per 1,000 mL of normal saline. However, in patients with contraindications to heparin—such as heparin allergies, antithrombin III deficiency, or a history of heparin-induced thrombocytopenia (HIT)—alternative anticoagulation strategies, such as citrate-based Acid

Citrate Dextrose Solution A or ACD-A or “Citrate: for short, are recommended. ACD-A functions by chelating calcium and inhibiting the initial steps of the coagulation cascade. For patients with compromised hepatic function, administering small doses of calcium may be necessary to counteract citrate toxicity.

### Centrifugation

Blood, a complex fluid comprising various components such as plasma, water, proteins, electrolytes, lipids, erythrocytes, leukocytes, and platelets, is separated by centrifugal force based on the relative densities of these components. Erythrocytes, being the most dense, migrate toward the outer walls of the centrifuge or bowl (Waters, 2005).

### Washing

The washing process involves passing a normal saline solution through the packed erythrocytes, effectively removing

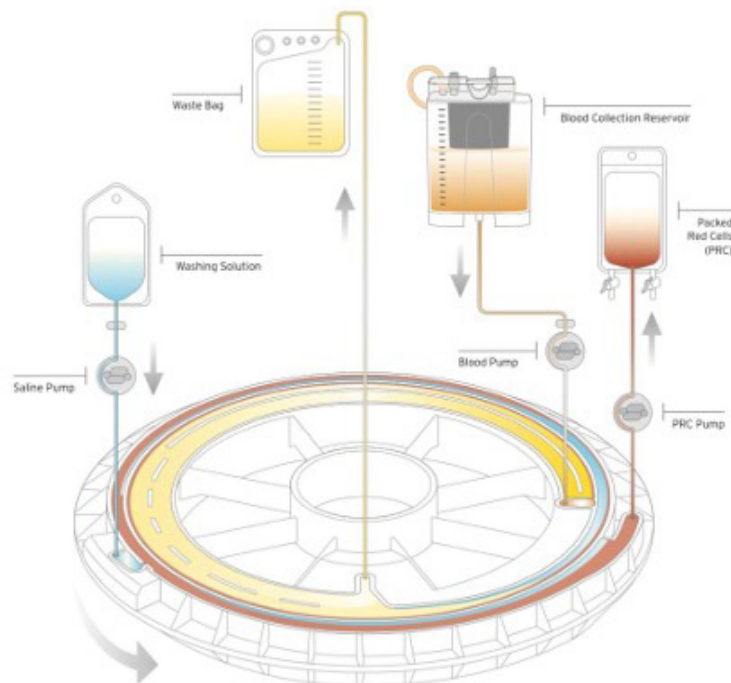
residual debris, agglomerates, lipids, anticoagulants, and free hemoglobin. This step is crucial for ensuring that the reinfused blood is free from harmful contaminants, thereby enhancing patient safety.

### Reinfusion

The reinfusion of concentrated erythrocytes must occur within six hours of processing to maintain cellular viability and clinical efficacy. Blood collected postoperatively should also be processed and reinfused within six (6) hours from the start of collection. The autotransfusionist must visually inspect the final product and take necessary precautions to eliminate the risk of air embolism before transfusion. Direct transfusion from the machine’s reinfusion bag should be avoided when possible. Instead, the collected cells should be filtered into a transfer bag, with air removed or 'burped' before transfusion. A minimum 170-micron blood filter is required for reinfusion, although the use of a 40-micron microaggregate filter is strongly advised to further reduce particulate matter. The final product should ideally exhibit a hematocrit between 50% and 80% (AABB, 2023).

## INDICATIONS AND ADVANTAGES

Autotransfusion offers several advantages, including the elimination of risks associated with transfusion-transmitted infections, transfusion reactions, immunosuppression, and



*Centrifuge disposables in the Fresenius-Kabi CATSmart Autotransfusion system. Image courtesy of Fresenius-Kabi*

alloimmunization. Additionally, it obviates the need for blood typing and cross-matching.

Autologous blood is generally acceptable to patients who refuse homologous transfusion on religious grounds, provided it remains within the closed circuit of their body, meaning it is not separated from the patient's circulatory system during processing. The rapid availability of autologous packed erythrocytes following blood loss, with a hematocrit exceeding 50%, is a significant clinical benefit.

The clinical efficacy of autotransfusion has been well-documented in cardiothoracic and vascular surgeries, liver transplantation, orthopedic procedures, and in the management of ruptured ectopic pregnancies. The following factors may guide the decision to use cell savers: when a patient has been cross-matched for allogeneic blood preoperatively, or when an estimated blood loss of 1,000 mL or the anticipated transfusion of one unit of blood is expected intraoperatively or postoperatively.

Advanced systems now offer plasma sequestration capabilities, allowing for the collection and separate processing of plasma from salvaged blood. This technique is particularly beneficial in surgeries involving significant losses of coagulation factors and plasma proteins, such as liver transplants, major trauma surgeries, and cases involving coagulopathies (Johnson & Brown, 2019).

## CONTRAINDICATIONS

Blood contaminated with agents such as betadine, hydrogen peroxide, distilled water, alcohol, fibrin glue, or collagen-based hemostatic agents should not be collected for autotransfusion. Similarly, surgical site contamination with substances such as meconium, urine, intestinal or gastric contents, bile, or amniotic fluid renders the blood unsuitable for reinfusion. In cases where malignant tumors are present, the use of cell savers may be contraindicated; however, a risk-benefit analysis should be conducted, with the final decision resting with the attending physician (Mynster & Nielsen, 2000). Patients with certain hemoglobinopathies, including sickle cell disease, may also be unsuitable candidates for autologous cell salvage due to the altered rheological properties of their erythrocytes, which may compromise the efficacy of the salvaged product.

## QUALITY ASSURANCE STANDARDS

To ensure optimal clinical outcomes, the American Association of Blood Banks (AABB) has established rigorous

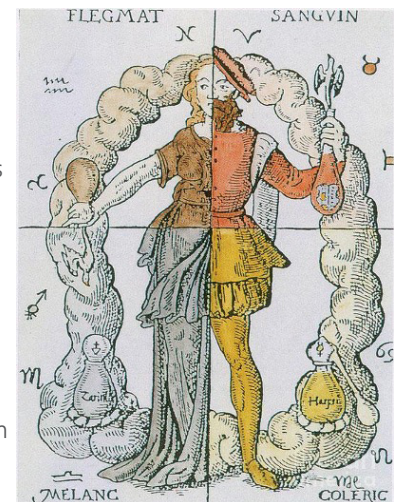
standards. These standards, published as Perioperative Autologous Blood Collection and Administration (AABB, 2023), are designed to ensure the safety and efficacy of cell salvage programs through comprehensive quality assurance protocols. Quality assurance testing encompasses critical aspects such as device performance, sterility, and the quality of salvaged blood. The AABB provides detailed guidelines for device management, staff training, and patient safety. Hematocrit levels should be tested quarterly on each machine in use and by each operator, with acceptable levels ranging between 50% and 80%. While specific standards for wash quality have not been universally established, testing for heparin washout, potassium washout, albumin removal, and free hemoglobin levels may serve as useful indicators.

## FROM HUMORS TO STANDARD OF CARE: TRACING THE EVOLUTION OF AUTOTRANSFUSION

The progression from rudimentary blood transfusion techniques to the sophisticated autotransfusion practices of today exemplifies the intersection of human ingenuity, scientific perseverance, and the often arduous path of medical discovery. Ancient civilizations, such as the Egyptians, Greeks, and Romans, attributed mystical properties to blood, believing it to be a vital substance.

Historical accounts detail how Egyptian royalty used blood baths for rejuvenation, while Roman gladiators consumed blood to enhance strength and stamina.

In 1492, Pope Innocent VIII reportedly received blood from three young boys in an attempt to restore his health, though it is believed this was likely an oral ingestion rather than an intravenous transfusion, as the circulatory system had not yet been discovered (Roets et al., 2019; Lindeboom, 1954). Andreas Libavius, a German physician, is credited with proposing the concept of intravenous blood transfusion in



*The Theory of the Four Humors originated in the works of Aristotle and was developed by Hippocrates. It became a mainstay of medical belief for two thousand years. The Greeks believed that the body was made up of four main components or Four Humors. These humors were blood, phlegm, black bile, and yellow bile. Image credit: Wellcome Collection, London*

1615, predating the discovery of the circulatory system. The first documented description of blood circulation by William Harvey in 1628 laid the groundwork for modern intravenous transfusion practices (Aird, 2011).

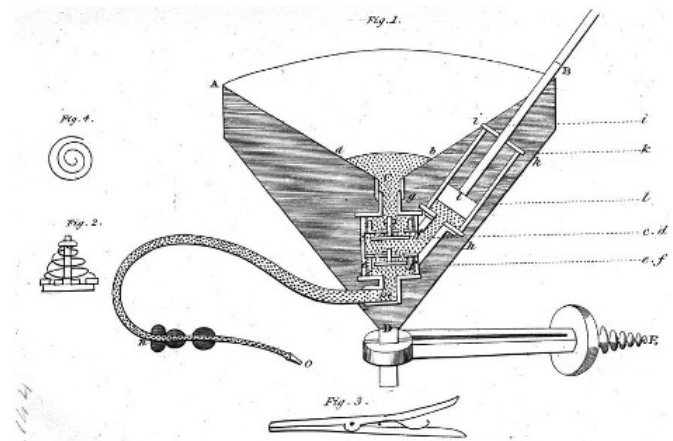
Experiments involving animal-to-human and human-to-human blood transfusions began in the mid-17th century, often with fatal outcomes. The notorious case of Jean-Baptiste Denis, who performed a lamb's blood transfusion on a mentally ill nobleman, resulting in the deaths of both man and lamb, underscores the perilous nature of early transfusion attempts. Denis was arrested after the widow accused him of poisoning her husband, though he was later acquitted (Tucker, 2011). Following this incident and others like it, several European countries prohibited transfusion practices and human experimentation, leading to a hiatus in transfusion-related research that lasted nearly 150 years.

Early animal studies encountered significant challenges with vein-to-vein transfusion due to clotting, prompting investigations into anticoagulation methods. Mechanical approaches, such as "defibrination," involved physically disrupting clots using devices like churns, wire whisks, and sieves. Chemical anticoagulants, including sodium phosphate, sodium bicarbonate, ammonia, paraffin-coated tubes, and hirudin, were also explored. Hirudin, a potent natural thrombin inhibitor, was discovered by John Berry Haycraft in 1884 and is derived from leech saliva. The practice of blending leeches to extract hirudin, prior to the isolation of the compound and advancements in asepsis, led to numerous febrile reactions and documented cases of toxicity and morbidity (Blumberg, Cholette, & Pietropaoli, 2010). The practice of sterilely isolating hirudin and marketing the medicine commercially did eventually occur in the 1950s.

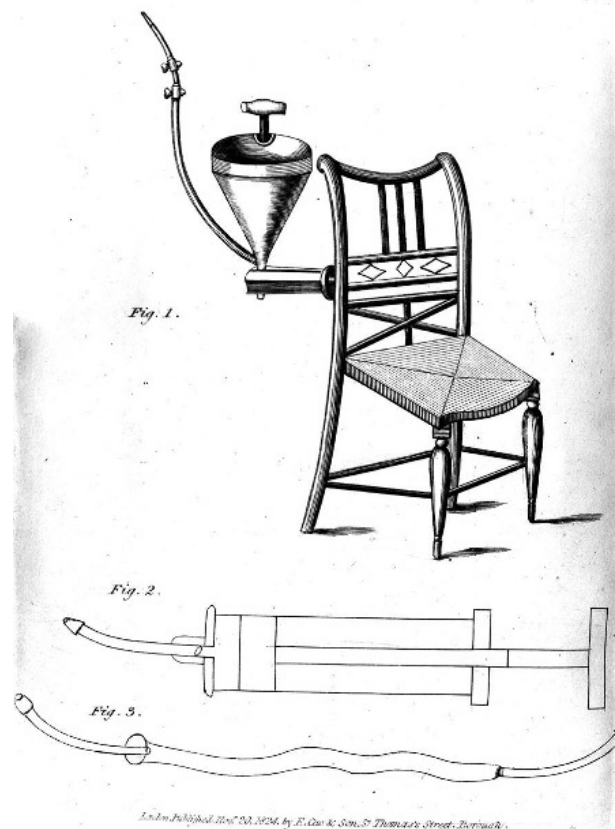
James Blundell, a London obstetrician, is often credited with the first autotransfusion, although this attribution may be inaccurate according to researcher Ashworth, who suggests that Blundell's writings do not conclusively indicate that the transfused blood was autologous (Ashworth & Klein, 2010). Nevertheless, Blundell made significant contributions to the field, publishing numerous articles in *The Lancet* and authoring a comprehensive textbook in 1824 that detailed the equipment, techniques, and adverse reactions associated with blood transfusion. Interestingly, Blundell expressed a preference for male blood donors, citing their lower likelihood of fainting, and emphasized the high risks associated with transfusion, reserving it as a last-resort therapy (Jones, 2003).

## THE FIRST DOCUMENTED AUTOTRANSFUSION

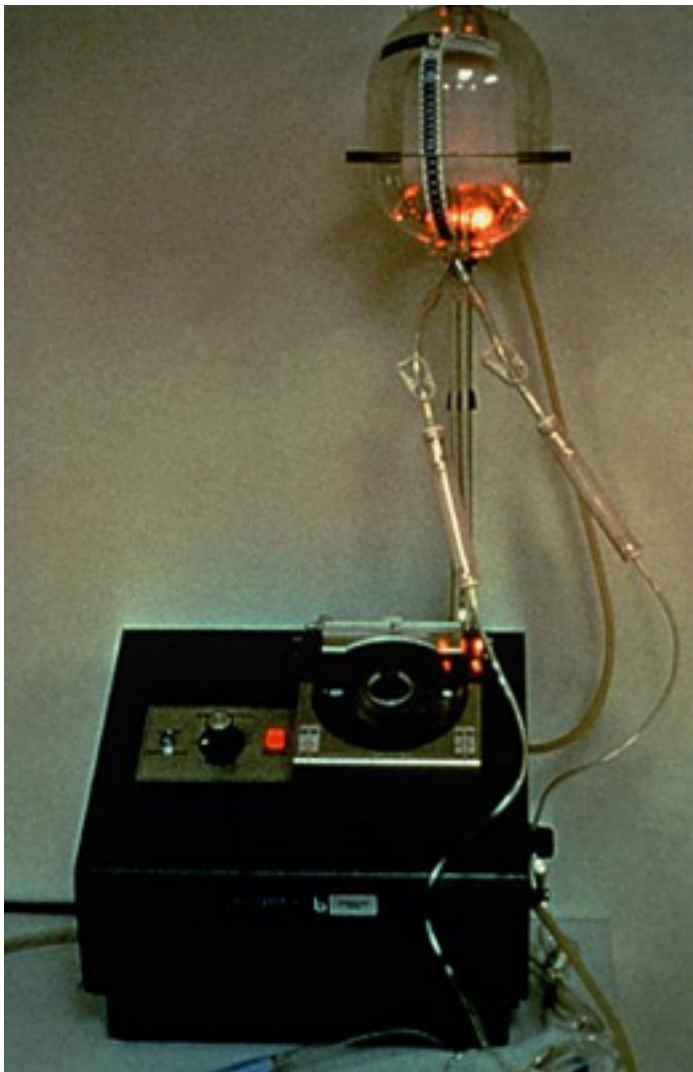
The first documented case of autotransfusion was reported by Dr. William Stewart Halsted in 1883. Halsted described a patient suffering from carbon monoxide poisoning, a common and often fatal condition at the time. Upon the patient's arrival at the clinic, unconscious with a strong pulse, minimal respiratory effort, and dilated pupils, Halsted withdrew blood from a radial artery. He then 'defibrinated,'



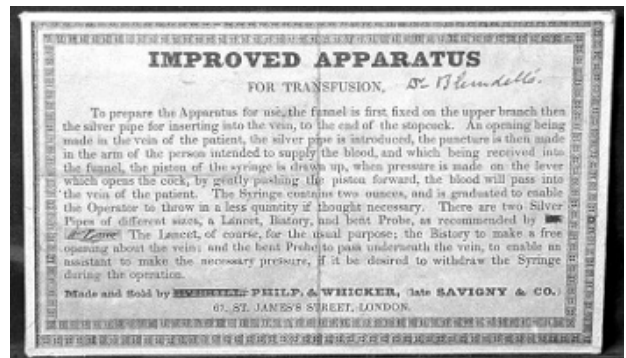
*Cross section of Blundell's Impellor.  
Image courtesy of Wellcome Collection, London.*



*Blundell's Impellor, 1824.  
Image courtesy of Wellcome Collection, London.*



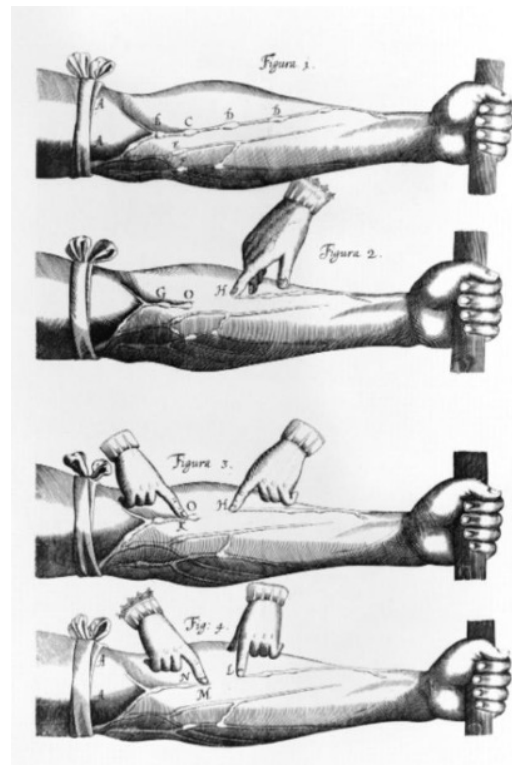
Dr. Klebenhof's Bentley ATS-100, circa 1970. This machine was pulled from the market after deaths associated with air embolism and disseminated intravascular coagulation (DIC). Image courtesy of Wellcome Collection, London.



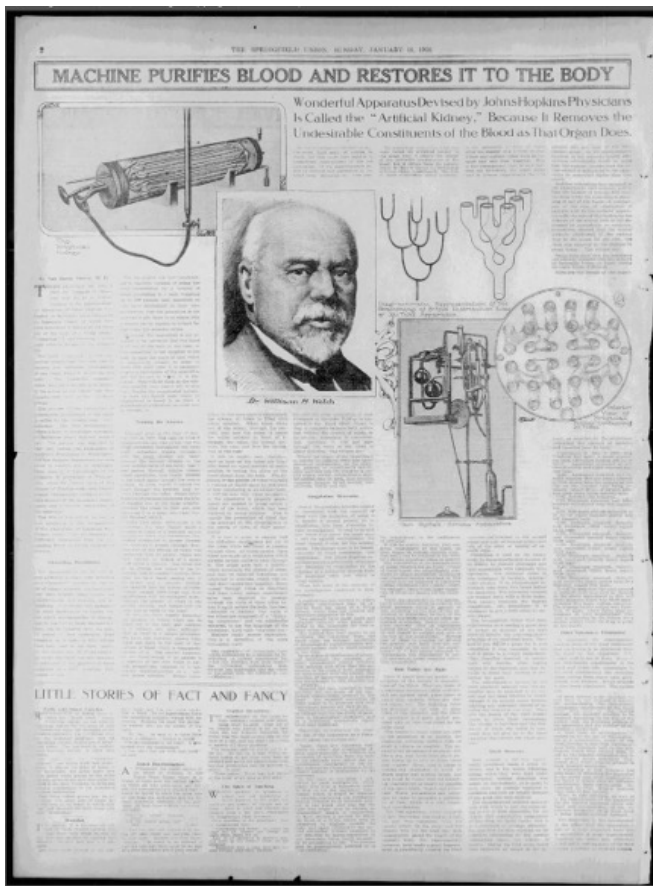
James Blundell's Gravitator. Image courtesy of Wellcome Collection, London.



Early 19th century obstetricians began research of blood transfusion and refusion to save the lives of women dying of perinatal hemorrhage. Image: James Blundell, "Observation on the Transfusion of Blood," *The Lancet*, Saturday, June 13, 1829. Image courtesy of Wellcome Collection, London.



Dr. William Harvey's (1578-1657) anatomical research on his discovery of the circulatory system. Image: Guilielmi Harvei, *Exercitatio anatomica de motu cordis et sanguinis in animalibus*, 1628. Image courtesy of Wellcome Collection, London.



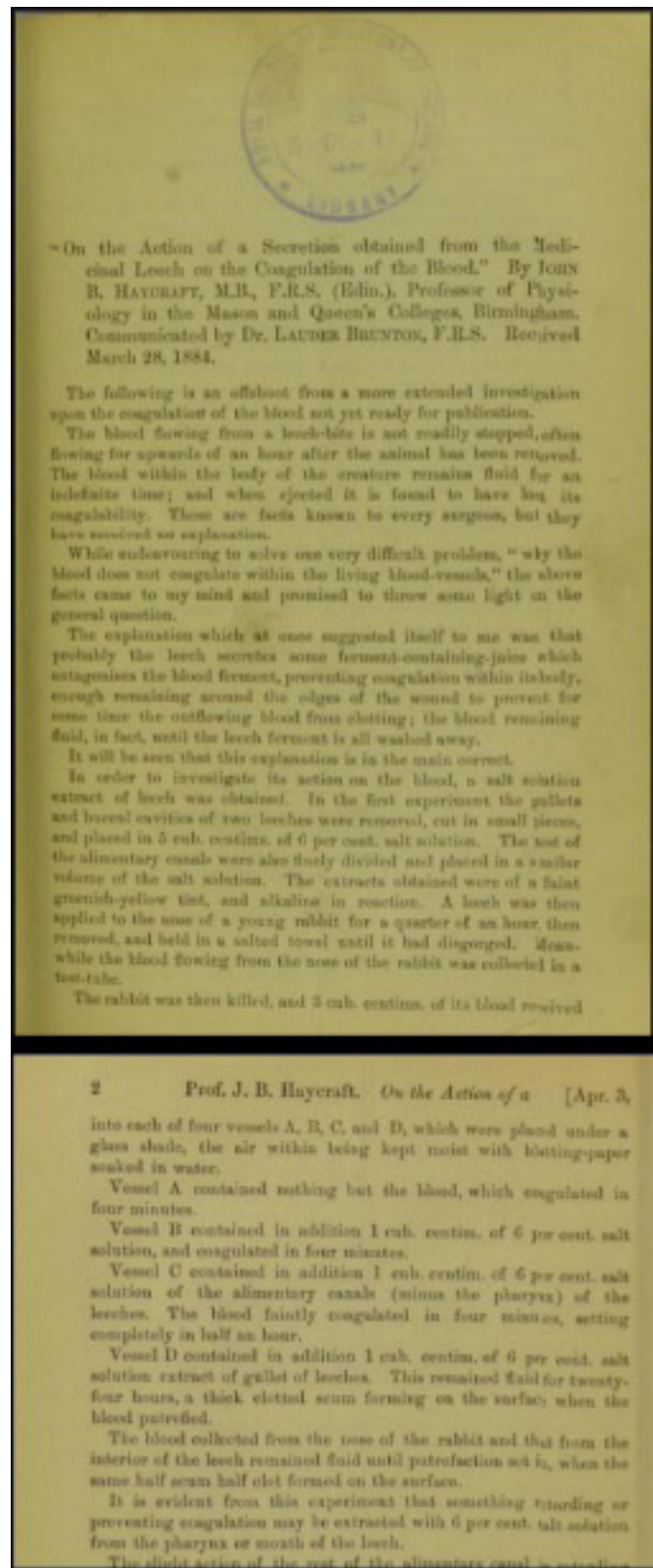
An example of the use of blood collection, filtration, and reinfusion from 1914 using Hirudin. The Springfield Union, January 18, 1914. Image courtesy of Wellcome Collection, London.

'strained,' and 'warmed' the blood before reinfusion. The patient showed some improvement, prompting Halsted to withdraw additional blood, which he mixed with donor blood prior to transfusion. The patient regained consciousness 27 hours later and continued to recover over the following six months. Although the precise contribution of the autotransfusion to the patient's recovery remains unclear, the case was considered a clinical success.

During World War II, autotransfusion was employed in 1927 for the first time during abdominal trauma surgery. The surgeon collected blood via suction or "mopping," used citrate for anticoagulation, and filtered the blood through cheesecloth. Between 1914 and 1934, autotransfusion became a common practice for managing significant blood loss in patients with ruptured ectopic pregnancies (Jones, 2003).

## THE EVOLUTION OF AUTOTRANSFUSION EQUIPMENT

In the early 19th century, Blundell developed a device known as the "impellor," which remained in use until the turn of the 20th century. While the equipment has undergone significant



On the action of a secretion obtained from the medicinal leech on the coagulation of the blood / by J.B. Haycraft ; [communicated by Dr. Lauder Brunton]. Public Domain Mark. Source: Wellcome Collection. <https://wellcomecollection.org/works/zrb7xad5>

advancements, the fundamental principles of blood collection, anticoagulation, and reinfusion have remained largely unchanged. By 1885, practitioners were utilizing sterile basins for blood collection, sodium phosphate as an anticoagulant, and syringes for reinfusion. In 1943, Arnold Griswold developed one of the first formal cell salvage devices, which suctioned blood into a bottle containing a cheesecloth filter and anticoagulant before reinfusion. At that time, clinicians had learned to avoid contaminants such as bile, tissue, fat, and bacteria (Tucker, 2011). In 1968, Wilson and Taswell introduced a suction machine with a centrifuge to separate erythrocytes and wash them with normal saline or lactated Ringer's solution. This machine also allowed for continuous reinfusion. Klebanoff and Dyer later added roller head pumps and filtered cardiomy reservoirs to the centrifuge machine, and by 1970, the Bentley Autotransfuser was being manufactured for commercial use in California. Unfortunately, the reinfusion pressure from the roller head pumps led to many fatal air embolisms. Subsequent developments addressed this risk, and by 1976, both Sorenson and Haemonetics had introduced improved cell saver autotransfusion systems.


## FUTURE PROSPECTS

The future of cell salvage technology is promising, with ongoing advancements aimed at enhancing efficiency,

reducing complications, and broadening the scope of application. Innovations include the development of miniaturized and portable cell savers for use in emergency and battlefield settings, integration with real-time blood analysis systems to ensure optimal erythrocyte quality, and the creation of automated systems that further minimize the need for manual intervention. Additionally, research is focused on refining the washing process

to more effectively remove contaminants, thereby ensuring the highest possible quality of salvaged blood for reinfusion.

## CONCLUSION

Intraoperative cell salvage has progressed from rudimentary blood transfusion practices to a sophisticated, life-saving technology in modern surgery. By comprehending and acknowledging the historical challenges and innovations that have shaped its development, we gain a deeper appreciation for the crucial role that autologous cell salvage systems play in contemporary medical practice. As technology continues to advance, cell salvage is poised to become an even more integral component of patient care. By ensuring safer and more efficient blood conservation strategies, this technology will likely play a crucial role in the future of surgery, providing life-saving solutions in increasingly complex medical environments. 

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# Continuing Education Quiz

PAGE 1 of 2

To test your knowledge on this issue's article, provide correct answers to the following questions on the form below. Follow the instructions carefully.

- 1. Which of the following is the primary benefit of intraoperative cell salvage?**
  - A. Reduction in surgery time
  - B. Decreased need for homologous blood transfusion
  - C. Increased surgical precision
  - D. Enhanced wound healing
- 2. During cell salvage, what is the recommended suction pressure to minimize erythrocyte destruction?**
  - A. 200 mm Hg or less
  - B. 100 mm Hg or less
  - C. 160 mm Hg or less
  - D. 300 mm Hg or less
- 3. Which anticoagulant is commonly used in cell salvage when a patient has a history of heparin-induced thrombocytopenia (HIT)?**
  - A. Heparin
  - B. Warfarin
  - C. Citrate
  - D. Aspirin
- 4. What is the primary purpose of the washing process in cell salvage?**
  - A. To reduce the volume of blood collected
  - B. To remove residual debris, anticoagulants, and free hemoglobin
  - C. To increase the concentration of platelets
  - D. To improve blood oxygenation levels
- 5. Which of the following situations is considered a contraindication for using cell salvage?**
  - A. Blood contaminated with meconium
  - B. Surgery involving liver transplantation
  - C. Cardiothoracic surgery
  - D. Orthopedic surgery with minimal blood loss
- 6. What is the recommended hematocrit range for the final product of autologous cell salvage before reinfusion?**
  - A. 30% to 50%
  - B. 50% to 80%
  - C. 80% to 100%
  - D. 40% to 60%
- 7. Which historical figure is credited with the first documented case of autotransfusion?**
  - A. Andreas Libavius
  - B. Jean-Baptiste Denis
  - C. James Blundell
  - D. William Stewart Halsted
- 8. In what year was the concept of intravenous blood transfusion first proposed, according to historical records?**
  - A. 1492
  - B. 1615
  - C. 1628
  - D. 1883
- 9. What is one of the most significant advancements in cell salvage technology that allows for use in emergency and battlefield settings?**
  - A. Integration with patient monitoring systems
  - B. Miniaturization and portability of cell savers
  - C. Enhanced blood oxygenation capabilities
  - D. Real-time blood coagulation analysis
- 10. What is the primary rationale for avoiding direct transfusion from the machine's reinfusion bag?**
  - A. To prevent air embolism
  - B. To ensure higher hematocrit levels
  - C. To allow for additional filtering of platelets
  - D. To decrease the risk of clotting

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- |            |             |
|------------|-------------|
| 1. A B C D | 6. A B C D  |
| 2. A B C D | 7. A B C D  |
| 3. A B C D | 8. A B C D  |
| 4. A B C D | 9. A B C D  |
| 5. A B C D | 10. A B C D |

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