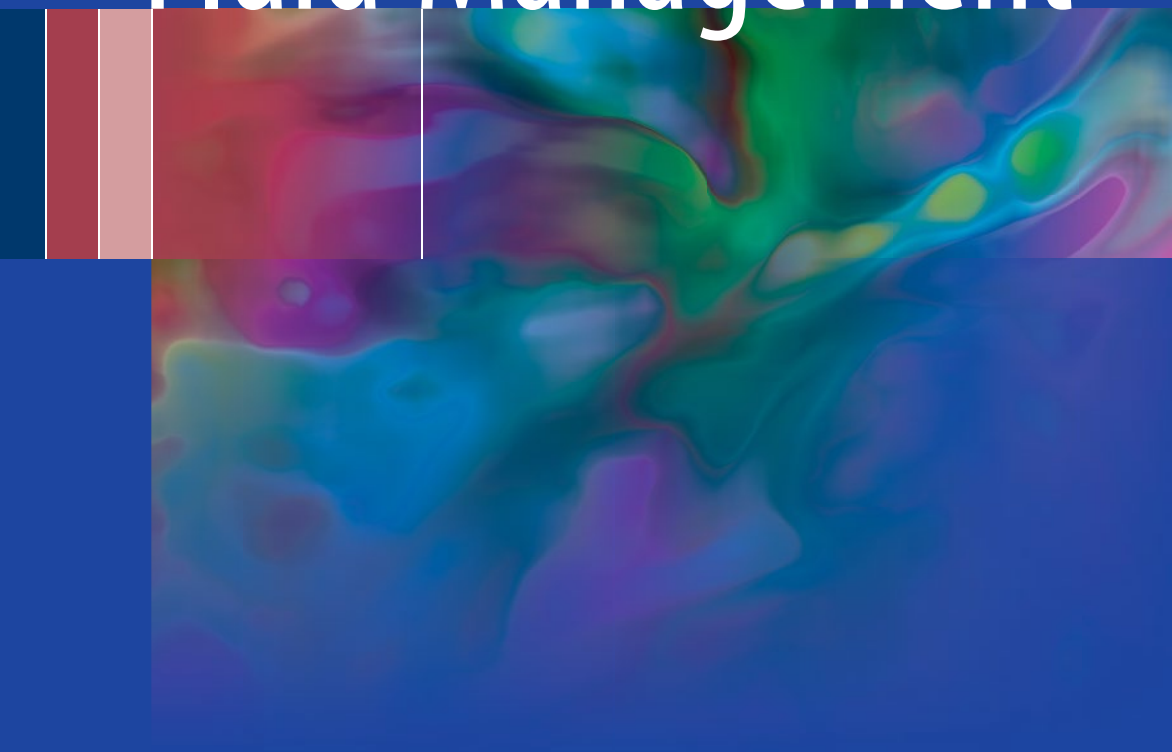
Ehab Farag · Andrea Kurz
Editors

Perioperative Fluid Management



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To my daughter Becky for her compassionate, listening ear, and assistance in many of my publications.

– Ehab Farag

Foreword

Perioperative fluid management has been a debated topic for decades within the anesthesia, surgical, and critical care literature. The "classic" approach to fluid administration was based upon the duration of fasting, patient weight, duration of surgery, and extent of tissue disturbance. The high degree of evolution that has occurred on this topic is evidenced by perusing the contents of this book.

Drs. Ehab Farag and Andrea Kurz have assembled an incredible group of recognized authorities and experts in this field. Collectively, they have amassed one of the world's most comprehensive collections of evidence-based literature that supports the newest concepts and approaches to perioperative fluid management. Yet this book also provides a true historical perspective, beginning with the contribution of Dr. Elizabeth Frost, followed by chapters on the revised Starling principle and functions of endothelial glycocalyx. The content of this book is deep and broad in discussing all aspects of perioperative fluid management, thorough, and comprehensive. No "stone is left unturned" in this discussion.

I have no doubt that this book will be used as a great reference for other academic endeavors in this field, making it a "must read" and necessary inclusion to the library of every anesthesiologist, surgeon, and critical care physician caring for perioperative patients.

The overall design of this book is two parts. The first part covers the overall process, techniques for monitoring and management, restricted vs liberal administration strategies, crystalloid vs colloid, patient outcome, and the role of fluid management in enhanced recovery protocols. The second part provides a case-based approach to fluid management in specific patient scenarios, broadly characterized as abdominal, orthopedic, neurological, and septic shock.

The topic of perioperative fluid management has important implications on morbidity, mortality, enhanced recovery, and perioperative outcomes. This book comes at a time when financial pressures are closely linked to patient outcomes with the evolution of bundled-payment models. A rational, evidenced-based, best practice approach to fluid management can have a significant impact upon overall patient outcomes and hence is a topic worthy of complete understanding in the manner in

which Drs. Farag and Kurz have undertaken. They are to be congratulated for their outstanding contribution to the literature.

On a personal note, I am proud to be associated with the many authors of this book who work at the Cleveland Clinic. Their outstanding contributions to this textbook are a testament of their dedication and daily contribution toward patient care that allows our institution to care for a wide variety of critically ill patients within many surgical subspecialty areas. Their collaborative approach to this book illustrates the way they "act as a unit" with other physicians in the perioperative care of our patients within a clinical approach that truly puts "patients first."

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Preface

With the establishment of the society of microcirculation in the 1980s, our understanding of microcirculation and tissue perfusion has fundamentally changed. The discovery of functions of endothelial glycocalyx and its essential role in maintaining the intact vascular barrier by Professors Curry and Michel has led to a new era in perioperative fluid management. The Starling Principle that was considered sine qua non for governing tissue perfusion since the 1920s and was written on a tablet of stone in medical textbooks was built on a false assumption of the structure of the blood vessels. Therefore, the Revised Startling Principle has replaced it, thanks to Drs. Curry and Michel's work in the field of microcirculation. The concept of liberal perioperative fluid management to compensate for the third space fluid loss was shown to increase the incidence of mortality and morbidity, especially in critically ill patients. The restrictive fluid management that properly should be named "normovolemic fluid management" has become an integral part of the enhanced recovery after surgery to improve the patients' perioperative outcomes. In this first edition of the *Perioperative Fluid Management* book, we tried our best to present the most comprehensive coverage of the most recent evidence-based medicine of fluid management written by world-renowned experts in the field. The book chapters cover different facets of fluid management, such as the history of intravenous fluid, goal-directed fluid management, balanced and unbalanced solutions, the dilemma with the use of hydroxyethyl starch solutions, the perioperative use of albumin, the effect of fluid overload on perioperative mortality and morbidity, and many more. We are honored to have the chapters for revised Starling Principle and endothelial glycocalyx written by the founding fathers of the modern science of microcirculation Drs. Curry and Michel who rewrote the story of the science of this field. Moreover, we added case scenarios for fluid management in different clinical settings to help guide the fluid management in a practical way.

We would like this book to benefit the understanding and fluid management of perioperative physicians.

At the end, we would like to express our gratitude to our colleagues who authored the book chapters for their efforts and hard work. In addition, we would like to thank Ms. Maureen Pierce our developmental editor and the Springer publishing team for all their help and support during the publishing process of this book.

Cleveland, OH

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Part I
Fundamentals of Fluid Management

Chapter 1
A History of Fluid Management

Elizabeth A.M. Frost

Abstract A history of fluid management is discussed focusing on the following key points. Bloodletting has been performed for more than 2000 years and is still used today, albeit for different reasons. While bloodletting was ordered by physicians, it was usually carried out by barber surgeons, thus dividing the two. Circulation of blood was not appreciated until William Harvey in the first century, and it was not immediately accepted as it was contrary to the teachings of Galen and others. The concept of the need for fluid replacement rather than bloodletting grew out of the worldwide cholera epidemic of the nineteenth century. Only over the past 60 years have fluids routinely been given intraoperatively.

Keywords History • Blood • Fluid management • Bloodletting • Circulation • Fluid replacement • Cholera • Intravenous • Transfusion

Key Points

1. Bloodletting has been performed for more than 2000 years and is still used today, albeit for different reasons.
2. While bloodletting was ordered by physicians, it was usually carried out by barber surgeons, thus dividing the two.
3. Circulation of blood was not appreciated until William Harvey in the first century, and it was not immediately accepted as it was contrary to the teachings of Galen and others.
4. The concept of the need for fluid replacement rather than bloodletting grew out of the worldwide cholera epidemic of the nineteenth century.
5. Only over the past 60 years have fluids routinely been given intraoperatively.

> The life of the flesh is the blood (*Leviticus* 17:11–14)
>
> Take drink…this is my blood which is shed for you for the remission of sins (*Matthew* 26)

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Earliest Times

Long before biblical times, blood and body fluids were believed to have magical powers. Blood was the cornerstone of life and regarded as a gift. Hence, it was often used in sacrificial offerings to appease the gods. The Sumerians of Mesopotamia (4th–2nd millennium BCE) considered the vascular liver as the center of life [1, 2]. The priests of Babylon taught that there were two types of blood: bright red day blood in the arteries and dark night blood in the veins. In the *Yellow Emperor's Classic of Internal Medicine*, the *Nei Ching Su Wen*, an ancient Chinese text compiled about 4500 BCE, the heart and pulse were connected and all the blood was said to be under the control of the heart and flowed continually until death (Fig. 1.1) [3].

Egyptian physicians were aware of the existence of the pulse and also of a connection between the pulse and heart. The Smith Papyrus, ascribed by some to Imhotep who lived around 2650 BCE and was the chief official of the Pharaoh Dosier, offered some idea of a cardiac system, although perhaps not of blood circulation (Fig. 1.2) [4]. Distinction between blood vessels, tendons, and nerves was not made. A theory of "channels" that carried air, water, and blood to the body was

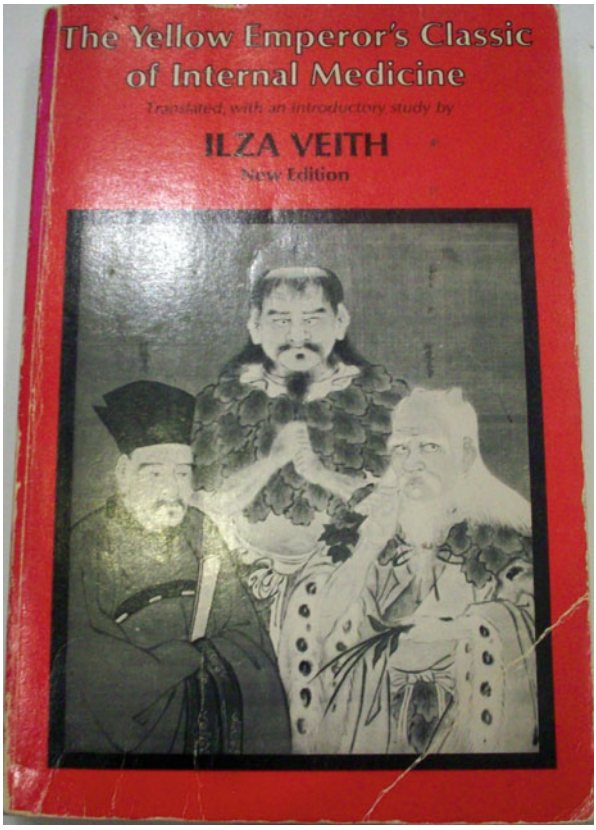

Fig. 1.1 *The Yellow Emperor's Classic of Internal Medicine*. On page 34, one reads, "When people lie down to rest, the blood flows back to the liver"

Fig. 1.2 The Edwin Smith Papyrus. The original belongs to the New York Academy of Medicine and is presently on loan to the Metropolitan Museum in New York

analogous to the River Nile; if the river became blocked, crops were unhealthy. This principle was applied to the body: If a person was unwell, laxatives should be used to unblock the "channels."

Greek philosophers began investigations into the circulation also in the 2nd millenium BCE. Aristotle, a physician of the fourth century BCE, believed that blood was manufactured in the heart and then distributed to other tissues [1]. Erasistratus, an anatomist of the third century BCE, is credited for his description of the valves of the heart. He also concluded that the heart was not the center of sensations, but instead functioned as a pump [5, 6]. He distinguished between veins and arteries but believed that the arteries were full of air and that they carried the "animal spirit" (*pneuma*). But Galen, in the second century CE, disagreed with Erasisratus, believing that blood was made in the liver and that it moved back and forth until it was consumed [7]. This theory remained unchallenged until 1628 when William Harvey published his treatise, *De Motu Cordis* [8].

Between the first and sixth centuries CE, consumption of the blood of Roman gladiators was said to cure epilepsy [9]. After the banning of gladiatorial fighting around 400 CE, it became the practice to drink the blood of executed prisoners, especially if they were beheaded. Epileptic patients were described as crowding around the scaffold, cups in hand, waiting to "quaff the red blood as it flows from the still quavering body of a freshly executed criminal" [10]. There are some reports that this supposed cure for the "falling sickness" existed until the nineteenth century [9].

Consuming blood was also thought to restore youth. A fifteenth-century physician noted: "There is a common and ancient opinion that certain prophetic women who are popularly called 'screech-owls' suck the blood of infants as a means, insofar as they can, of growing young again. Why shouldn't our old people, namely those who have no [other] recourse, likewise suck the blood of a youth?—a youth, I say who is willing, healthy, happy and temperate, whose blood is of the best but perhaps too abundant. They will suck, therefore, like leeches, an ounce or two from a scarcely-opened vein of the left arm; they will immediately take an equal amount of sugar and wine; they will do this when hungry and thirsty and when the moon is waxing. If they have difficulty digesting raw blood, let it first be cooked together with sugar; or let it be mixed with sugar and moderately distilled over hot water and then drunk" [11].

Suggested as perhaps the first attempt at blood transfusion, three young boys were bled and the blood given to Pope Innocent VIII by his Jewish physician Giancomo di San Genesio in 1492 [1, 2]. It is, however, more likely that the pope drank the blood. Nevertheless, the boys and the pope all died and the physician disappeared. It is also possible that the story was circulated as an anti-Semitic campaign as the pope was very ill at the time.

Bloodletting

Bloodletting derived from a belief that proper balance to maintain health was required between the four humors—blood, phlegm, black bile, and yellow bile—based in turn on the Greek philosophy of the elements of water, air, fire, and earth [12, 13]. Galen felt that blood was the dominant humor and the one most to be regulated. To balance the humors required removal of blood or purging. Aretaeus of Cappadocia, probably a first-century CE contemporary of Galen, advocated venesection for the treatment of "phrenetics": "If the delirium and fever have come on in the first or second day it will be proper to open a vein at the elbow, especially the middle" [14].

Bloodletting was the most frequently performed medical practice for more than 2000 years (Fig. 1.3) [15]. While trepanning of the skull allowed evil spirits to be released from the head, bloodletting facilitated the removal of the demons that caused disease from other parts of the body. The Egyptians used the technique at least by 1000 BCE, followed by the Greeks and Romans [12, 13]. While teaching that many diseases were caused by an overabundance in the blood, Erasistratus advocated initial treatment with vomiting, starvation, and exercise [6]. Overabundance or plethora was recognized by headache, tiredness, seizures, and fever. The practice of bleeding may have derived from the belief that menstruation occurred to "scourge women of bad humors" as taught by Hippocrates and Galen. Moreover, premenstrual cramps and pain were often relieved when blood flowed [1, 7, 16].

Precise instructions dictated how much blood should be removed based on age, general health, the season, and the weather. Either arterial or venous blood was

Fig. 1.3 Iatros, an ancient Greek word for "physician," is depicted on this old Grecian vase, bleeding a patient. The Peytel Arybalos, 480–470 BC, Louvre, Dpt.des Antiquites Grecques/Romaines, Paris. Photographer: Marie-Lan Nguyen, 2011 (Reprinted under Creative Commons license. https://creativecommons.org/licenses/by/3.0/deed.en)

drained depending on the disease. Blood vessels were identified depending on which organ they drained. The more severe the illness, the greater amount of blood was to be removed. Different religions laid down specific rules as to appropriate days; for example, select saints' days in the Christian calendar. Specific days of the week were also identified in the Talmud. The Talmud recommended specific days of the week and of the month for bloodletting [17]. Bleeding charts aligned bodily bleeding sites with the planets. Bloodletting was even used to treat hemorrhage before surgery and during childbirth to prevent inflammation. The amount of blood estimated to be in a limb was removed prior to amputation of that limb.

George Washington, the first US president, died after having 3.75 l of blood removed from his body within a 10-h period as treatment for *cynanche trachealis* as noted by Drs. Craik and Dick (most likely a peritonsillar abscess) [18].

Bloodletting was usually ordered by physicians but carried out by barber surgeons, thus dividing physicians from surgeons. The red-and-white-striped barber's

Fig. 1.4 Bloodletting woodcut from *Officia M.T.C* Cicero, 1531 (Source: Wellcome Library, London. Wellcome Images. Reproduced under Creative Commons Attribution 4.0 International license. https://creativecommons.org/licenses/by/4.0/)

pole represented gauzes wrapped around a stick [13]. The practice was standard treatment for all ailments, both prophylactically and therapeutically and persisted into the twenty-first century (Figs. 1.4 and 1.5) [13, 19, 20].

Pierre Alexander Louis, a French physician of the nineteenth century, disagreed that fevers were the result of inflammation of the organs and bloodletting was an effective treatment for pneumonia [21, 22]. He published a paper in 1828 (expanded in 1834 to a book-length treatise in the *American Journal of Medical Sciences* entitled "An essay on clinical instruction"), demonstrating the uselessness of bloodletting. He met with strong resistance by physicians who refused to wait for reviews to determine if current treatments worked or change their practices of centuries. Gradually Louis' "numerical method" added objectivity to how patients should be treated to improve outcomes. He used averages of groups of patients with the same illness to determine effectiveness of therapies and accounted for age, diet, severity of illness, and treatments other than bloodletting. He also wrote of "averages" and "populations" and thus began the concept of "statistical probability."

During the early nineteenth century, leeches became popular (Fig. 1.6a, b). "Leech collectors," usually women, would wade into infested ponds, their legs bare. The leeches would attach themselves and suck several times their body weight of blood and then fall off, to be collected and sold to physicians [23]. In the 1830s, England imported about six million leeches annually for bloodletting purposes from France. Initially a very inexpensive treatment, scarcity of the little worms drove the price up and the treatment became less popular [23].

Fig. 1.5 An old photo of bloodletting during the nineteenth century. From the collection of the Burns Archive, PD-US

Beginnings of Intravenous Therapy

In 1242, an Arabian physician, Ibn al Nafis, accurately described the circulation of the blood in man [24]. He wrote: "The blood from the right chamber of the heart must arrive at the left chamber but there is no direct pathway between them. The thick septum of the heart is not perorated and does not have visible pores or invisible pores as Galen thought. The blood from the right chamber must flow through the vena arteriosa to the lungs, spread its substances, be mingled there with air, pass through the arteria venosa to reach the left chamber of the heart and there form the vital spirit…" [24].

Nevertheless, credit for the discovery of the circulation is generally given to William Harvey. He concluded: "The blood is driven into a round by a circular

Fig. 1.6 (**a**) An artistic representation of a woman who is self-treating with leeches from a jar (Source: van den Bossche G. *Historia medica, in qua libris IV. animalium natura, et eorum medica utilitas esacte & luculenter.* Brussels: Joannis Mommarti, 1639. US National Library of Medicine). (**b**) Leeches as they were purchased in a jar

motion and that it moves perpetually and hence does arise the action and function of the heart, which by pulsation it performs" [8].

Harvey first presented his thesis, *De Motu Cordis*, at the Lumleian lecture (a series started in 1582) of the Royal College of Physicians in 1616 [25]. His insights evolved over several years thereafter and were finally published in 1628 in Latin in a 72-page book in Frankfurt, probably because that venue was host to an annual book fair that would allow the work greater attention [8]. The treatise was not translated into English until 1653. Such views of the circulation were contrary to the teachings of Galen and thus Harvey's work was not immediately appreciated. Indeed, his practice suffered considerably, but no doubt the dedication of the book to King Charles I, to whom he was personal physician, helped in the ultimate acceptance of his conclusions and set the stage for intravenous therapy and fluid administration. Harvey did not know of the capillary system, the discovery of which is later ascribed to Marcello Malpighi, but he did describe fetal circulation [24].

Andreas Libavius, a German alchemist, imagined how blood could be taken from the artery of a young man and infused into the artery of an old man to give the latter vitality. Although he described the technique quite accurately in 1615, there is no evidence that he actually transfused anyone [1, 24]. The same can be said for the Italian, Giovanni Colle da Belluno, who mentioned transfusion in 1628 in his writings on "methods of prolonging life" [24].

Perhaps the first person to conceive of transfusion on a practical basis was the Vicar of Kilmington, in England, the Rev. Francis Potter [26]. Described as a reclusive eccentric, he was befriended by John Aubery, a close acquaintance of Harvey. Aubery an English antiquary and writer, recorded of Potter in 1649: "He then told me his notion of curing diseases by transfusion of bloud out of one man into another, and that the hint came into his head reflecting on Ovid's story of Medea and Jason, and that this was a matter of ten years before that time" [27].

Potter used quills and tubes and attempted transfusion between chickens but with little success.

Francesco Folli, a Tuscan physician, claimed to be the originator of blood transfusion [28]. He was aware of Harvey's work and felt it possible to cure all diseases and make the old young by transfusing blood. At the Court of the Medici he had given a "demonstration" of transfusion (it actually may only have been by diagrams) to Ferdinand II, Duke of Tuscany, who was not impressed and dismissed Folli. The latter went into seclusion and was unaware of the several advances by Richard Lower, Jean Baptists Denys, and others in the intervening years before he rushed to print a book, *Stadera Medica* (the Medical Steelyard, Florence, GF Cecchi, 1680), in which in a second section "Della Trasfusione del sangue" he asserted his claim as the inventor. He weighed the pros and cons of blood transfusion writing: "Discovered by Francesco Folli and now described and dedicated to His Serene Highness, Prince Francesco Maria of Tuscany." He postulated that 20 young men as donors could allow the patient to get fresh blood over a considerable time. He described his apparatus as a funnel connected by a tube from a goat's artery with a gold or silver cannula in the patient's arm [24]. Later he recanted and noted that it would be impertinent of him to give directions about an operation that he himself had never attempted [28].

Richard Lower, a Cornish physician, is credited as the first to perform a blood transfusion between animals (xenotransfusion) and from animals to man [29, 30]. Working with Christopher Wren, he performed a successful transfusion in 1665 by joining the artery of one dog to the vein of another by means of a hollow quill. Lower's major work, *Tractatus de Corde*, was published in 1669 and traced the circulation through the lungs, differentiating between arterial and venous blood. Believing that patients could be helped by infusion of fresh blood or removal of old blood, Lower transfused blood from a lamb to a mentally ill man, Arthur Coga, before the Royal Society on November 23, 1667. The procedure was recorded in Samuel Pepys' diary:

> …with Creed to a tavern and a good discourse among the rest of a man that is a little frantic that the College had hired for 20 shillings to have some blood of a sheep let into his body…I was pleased to see the person who had had his blood taken out…he finds himself better since but he is cracked a little in his head [2].

The same year, a French physician, Jean Baptists Denys, had administered the first fully documented human blood transfusion on June 15, 1667 [31, 32]. Using sheep blood, he transfused about half a pint into a 15-year-old boy, who had been bled with leeches 20 times (Fig. 1.7). Surprisingly, the boy recovered. Denys' second attempt at transfusion was also successful. However, his third patient, Baron Gustaf Bonde, died. Later in 1667, undeterred, Denys transfused calf's blood to Antoine Mauroy, who also died. Denys was accused by Mauroy's wife of murder. He was acquitted, and it was later found that the patient had died of arsenic poisoning. But considerable controversy arose and in 1670 blood transfusions were banned until the first part of the nineteenth century (around 1818) when James Blundell, using only human blood, saved a number of postpartum women who had almost

Fig. 1.7 Early transfusions were carried out between animals and humans. In this early illustration, blood is transfused from a lamb into a man. Wellcome Library, London (Reprinted under Creative Commons Attribution only license CC BY 4.0 http://creativecommons.org/licenses/by/4.0/)

bled out. He wrote: "appalled at my own helplessness at combating fatal hemorrhage during delivery" [2].

Blundell experimented by exsanguinating dogs and then reviving them by transfusing arterial blood from other dogs. He concluded that blood replacement had to be species-specific using initially vein-to-vein transfusion (Fig. 1.8). He later introduced the use of the syringe, noting that air must be removed and the problem of clotting: "…the blood is satisfactory only if it allowed to remain in the container for but a few seconds" [24].

Only with the discovery of the four groups of blood by Karl Landsteiner in 1900 did transfusion become safer and popular again.

Intravenous Infusions of Drugs and Fluids: Mainly in Dogs

Sir Christopher Wren, along with Robert Boyle, experimented extensively with intravenous administrations of many substances in animals [33]. An animal bladder attached to two quills was designed to infuse beer, wine, opium, and other drugs. A large dog was selected. Venous access was achieved and the vein stabilized with a brass plate. As reported in one of the initial experiments, opium and alcohol were injected (tincture of opium, which had long been used orally) resulting in a brief