

The history of peripheral intravenous catheters : How little plastic tubes revolutionized medicine

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Key words : Peripheral venous catheterization ; equipment, venous access device, transfusion, parenteral nutritional, medical history.

INTRODUCTION

If the great 16th century French surgeon, Ambrose Paré, who stopped the practice of pouring boiling oil into gunshot wounds, were to return today, what would impress him most about the evolution of medicine ? We might suggest three achievements : our ability to look into any corner of the body using imaging and scoping techniques, the vast range and specificity of drugs in our current armamentarium and the omnipresence of tubes. Yes, tubes ! Nearly every hospital patient Paré would encounter would have a tube lodged in a vein, and much of the success of the first two technologies could be ascribed to these little plastic devices which have quietly revolutionized medicine. This paper will tell the story of this revolution, beginning with the fledgling attempts to exchange blood between persons in the Middle Ages through to the plastic devices of today which, in addition to delivering therapy, now protect patients from adverse events and users from blood-borne pathogens. In a follow-up paper (31) we will explore the procedures for using these devices and will suggest guidelines for best practices.

LATE MIDDLE AGES

Intravenous (IV) therapy evolved from the earliest attempts to transfuse blood and the two procedures have been intertwined throughout medical history. The first historic documentation (24) of attempted IV therapy was in 1492, by a doctor caring for Pope Innocent VIII in Rome. The Pontiff had an apoplectic stroke, grew weaker and then fell into a coma. His physician decided to give him an infusion of blood from three healthy young boys. No device was used. Their veins were simply

joined in anastomosis and blood was exchanged. Unfortunately, not only the pope but the three donors died. The physician was reportedly a Jew and the story has been used in anti-Semitic attacks by several Catholic authors, including Infessura and Raynaldus, claiming that the boys were a mere ten years old and had been promised only a ducat apiece. As late as 1870 Drinkard wrote that ‘...a Jewish daring innovator, whose name has not come down to us in memory of his deed, proposed to find the pontiff a fountain of juvenescence in the blood of three youths who died as martyrs to their own devotion and the practitioners zeal’ (9). We could be forgiven for dismissing this whole account as apocryphical, the equivalent of a modern urban legend. In any case, the concept of IV transfusion was not revisited for over a hundred years (10).

The first textbook of chemistry was written at the end of the 16th century by a German naturalist, Andreas Libavious (1560-1616). His book, entitled *Alchemia* (1597) organized the prevailing knowledge of iatrochemist, or the use of chemical medicines. (21) Libavious proposes the concept of infusing blood from one person into another : ‘Let there be a young man, robust, full of spirituous blood, and also an old man, thin, emaciated, his

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strength exhausted, hardly able to retain his soul. Let the performer of the operation have two silver tubes fitting into each other. Let him open the artery of the young man, and put it into one of the tubes, fastening it in. Let him immediately after open the artery of the old man, and put the female tube into it, and then the two tubes being joined together, the hot and spirituous blood of the young man will pour into the old one as it were from a fountain of life, and all of his weakness will be dispelled' (9, 21). It is unclear if Libavious ever attempted such a fanciful procedure.

THE GREAT OXFORD DONS OF THE 1600'S

Giving opium IV to a dog was not an undergraduate prank in the 1600s. It was one of the first experiments performed by a remarkable generation of scientists who lived during the Puritan Revolution in Britain. Modern science began with this brilliant group which gathered at Oxford in the early and mid-1600's (3). Among them were William Harvey (1578-1657), who described circulatory physiology in *De Motu Cordis* (1628); Robert Boyle (1627-1691) of Boyle's law; Thomas Willis (1621-1675) discoverer of the Circle of Willis and one of the greatest anatomists of all time; Richard Lower (1632-1691), anatomist, physiologist and, arguably, the father of IV therapy; Christopher Wren (1632-1723), microscopist, physiologist, artist and renowned architect; John Locke (1632-1704), physician, political scientist and philosopher; and Robert Hooke (1631-1703) of Hooke's law, later resident scientist of the Royal Society.

Their experiments didn't start, however, with dogs, but rather with a servant girl. One winter morning in 1650, Anne Greene, a serving girl to Sir Thomas Read of Oxford, was sent to the gallows. She had been condemned for infanticide after her illegitimate baby, probably fathered by Read's grandson, was found dead shortly after birth. Although the baby was probably stillborn, Anne was convicted of murder and sentenced to hanging. Accepting her fate she pleaded with her friends to speed her death by beating her on the chest as she was being strung up. They reluctantly obliged. After the hanging her body was cut down and taken to the anatomy laboratory of Oxford University. As the dissection began, the "cadaver" began to move and moan. Among the startled students was an eighteen year-old named Christopher Wren, later the architect of more than fifty churches in Britain,

including St. Paul's Cathedral in London. Anne was successfully revived by these young students, and she became their pet patient. She went on to full recovery, was granted a pardon and lived to bear several more children.

A 1651 pamphlet immortalized the hanging in a poem composed by Christopher Wren, his first published work. The pamphlet bore the imposing 17th century title of: *Newes from the Dead. Or A True and Exact Narration of the miraculous deliverance of Anne Greene, Who being Executed at Oxford December 14. 1650. afterwards revived; and by the care of certain Physitians there, is now perfectly recovered. Together with the manner of her suffering, and the particular meanes used for her Recovery. Written by a Scholler in Oxford for the Satisfaction of a friend, who desired to be informed concerning the truth of the businesse. Whereunto are added certain Poems, casually written upon the Subject.* Anne Greene's revival apparently had a profound effect on Wren and his colleagues and inspired them to begin experiments in IV injections and transfusion.

Wren, using a quill and a pig's bladder, created the first working IV infusion device. His first experiment, in 1658, was to instil a mixture of wine, ale, opium and liver of antimony into a dog's veins. The dog tolerated it remarkably well and the experiment was repeated with other infusates. However, a series of problems emerged which forced an evolution in Wren's technology. As Felts notes, the 'study of the circulation of experimental animals was difficult in the beginning because vascular access was limited by blood clotting and primitive equipment. Quills could not be easily fixed into blood vessels and were neither firm nor durable enough. Silver, however, was malleable and firm, so that pipes of varying calibres could be fashioned and their ends rimmed for anchoring with ligatures. Such improved instrumentation allowed the exploration of many hitherto unplumbed fields by injection studies and administration of many agents' (13).

It was Richard Lower, Wren's colleague, who devised the new instruments and took over the transfusion work from the architect when he left Oxford to design his churches. Lower records that 'towards the end of February 1665 [I] selected one dog of medium size, opened its jugular vein, and drew off blood, until ... its strength was nearly gone ... Then, to make up for the great loss of this dog by the blood of a second, I introduced blood from the cervical artery of a fairly large mastiff, which had been fastened alongside the first, until

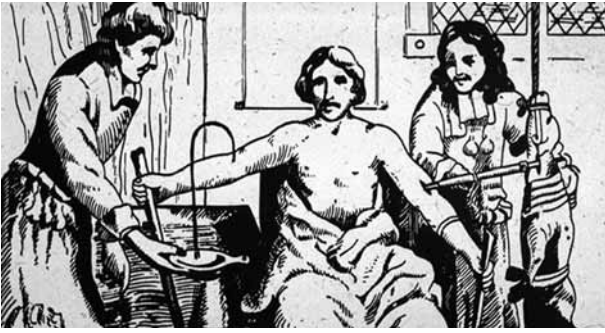


Fig. 1. — Early lamb blood transfusion

this latter animal showed ... it was overfilled ... by the inflowing blood' (22). Lower 'sewed up the jugular veins' and the dogs recovered 'with no sign of discomfort or of displeasure', the first successful transfusion between animals (13).

The honour of the first successful animal-to-human transfusion went to Dr. Jean Baptiste Denis, Professor of Philosophy and Mathematics in Paris on June 15, 1667 (9). Denis transfused 9 ounces of lamb's blood into a young man who was suffering from madness (33, 43 ; Fig. 1). Initially the patient tolerated it well, but subsequent transfusions produced the first documented adverse event. Denis gives a chillingly accurate description of what every haematologist will recognize as a transfusion reaction : 'As soon as the blood began to enter into his veins, he felt...heat along his arm, and under his arm pits.... His pulse rose presently, and soon after we observ'd a plentiful sweat over all his face. His pulse varied extremely at this instant, and he complained of a great pain in his kidneys, and that he was not well in the stomach, and that he was ready to choak unless they gave him his liberty.... When he awakened...he made a great glass full of urine, of a color as black, as if it had been mixed with the soot of chimneys'. The man's wife charged Denis with intentionally poisoning her husband, but he was exonerated and, in a turn-about worthy of today's courts, the wife herself was charged with her husband's poisoning !

Over-enthusiastic adoption of dubious transfusion practices lead to several deaths in Paris and the French parliament reacted by banning animal-to-human transfusions in 1668 (32).

However, there was no such ban in England and six months after Denis' first try, an animal-to-human transfusion was attempted by Lower in front of a gathering of Oxford scientists (14, 44). The recipient was Arthur Coga, a parson suffering from 'a harmless form of insanity' who had been

pleading for 'the blood of the lamb'. Obliging, Lower 'superintended the introduction in his arm at various times of some ounces of sheep's blood at a meeting of the Royal Society, and without any inconvenience to him' (13, 22). The blood from a quiet lamb was felt by many present to be an appropriate treatment for a troubled spirit. No transfusion reactions were noted and the pacified Coga refused any further interventions. The principle now proven, Lower set himself to solving the technicalities : how to do it better, what solutions to use when infusing and how to measure the effects.

Lower designed new devices for controlling blood flow when bleeding patients therapeutically as well as new devices for transfusions. Remarkably, his designs contain almost all the elements that have evolved into modern syringes, needles and IV catheters (Fig. 2).

Experimentation with the injection of medications into veins continued throughout the 1600's. The feather quills were modified to include metal tips, animal veins were harvested as tubing and various species of bladders were used as container bags. A Dutch work, *Clysmatic Nova* (published in Amsterdam in 1670), gives a full description of all the IV equipment that evolved during that period (32).

The British Royal Society, out of fear of adverse reactions, finally banned blood transfusions in 1668 and the Vatican followed suit in 1669. The ban on transfusions imposed by these groups, as well as that of the French government, had a devastating effect on the evolution of IV therapy and for over one hundred years there was scientific paralysis. Then in 1795 a daring American doctor, Philip Syng Physick, later acknowledged as the Father of Modern Surgery, became the first to suggest a human-to-human transfusion (33). It is unclear whether he actually attempted the procedure himself but he seems to be the first to have proposed such a technique, claiming it could reduce complications in obstetrical cases. Shortly afterwards Dr. James Blundell, a British obstetrician working at St Thomas's and Guy's Hospitals, performed a series of remarkable transfusions of human blood for the treatment of postpartum haemorrhage. In the first case, performed in 1818, he used the patient's husband as a donor, extracting a small amount of blood from his arm and, using a syringe, successfully transfused it into the wife (6). By all accounts the procedure was a success. Between 1825 and 1830, Blundell performed ten documented transfusions, five of which proved beneficial to his patients, and he published the

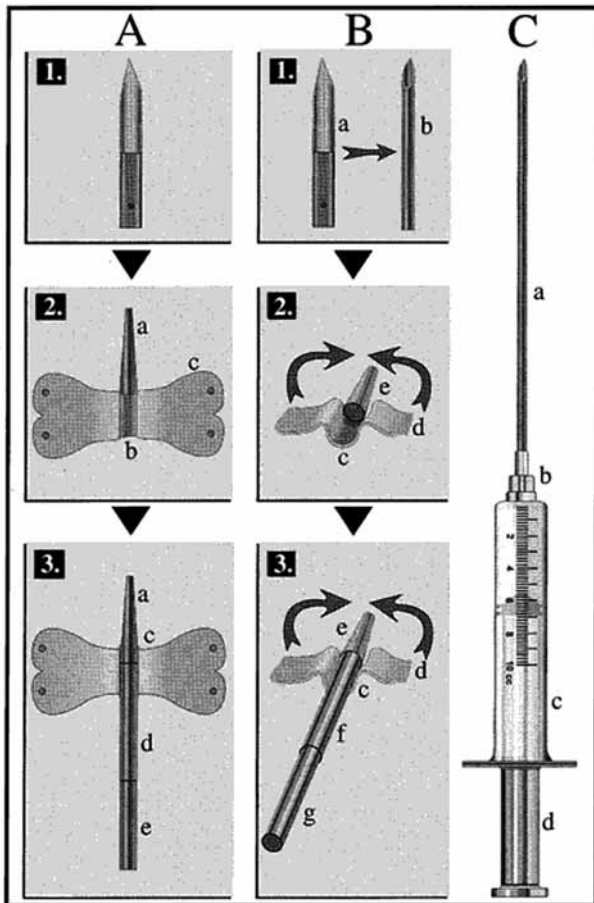


Fig. 2. — The evolution of Lower's instruments into a modern syringe and needle. A. Lower's original instrument designs. A1. Lower's lancet for venesection. A2 and A3. Lower's apparatus for transfusion: tapered silver tube (a) for placement in blood vessel, groove in pipe (b) for placement of connector from infusion, flange (c) to fix tube by suture, connector or emissary tube (d), and wooden rod (e) to close emissary tube while preparing infusion. B. Changes made to Lower's instruments. B1. The lancet (a) is rolled to become a tube (b) with a pointed end. B2. The groove (c) and the flanges (d) are truncated, rolled, and fused to form the hub of the needle. The silver pipe (e) is altered to become the needle. B3. The connector (f) and the wooden rod (g) become the barrel and plunger of the syringe. C. The modern syringe with needle. The lancet and silver pipe have become the needle (a). The transformed flange has become the needle hub (b). The connector, tipped and scored, has become the barrel of the syringe (c). The wooden rod has become the plunger (d).

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results (7). Blundell also invented various instruments for performing IV transfusions. One device, called the 'Impellor', infused blood under pressure to the recipient; the 'Gravitator' was a gravity-feed apparatus (Fig. 3). He describes it in a 1829 *Lancet* article (7):

The object of the Gravitator is, to give help... by transmitting the blood in a regulated stream

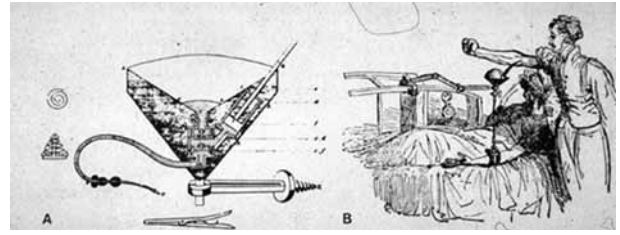


Fig. 3. — Blundell's transfusion devices included the impellor (A), which consisted of a cup, tube, and syringe; and the gravitator (B), consisting of a receptacle held high above the patient with an attached tube through which the blood was injected into the patient.

from one individual to another, with as little exposure as may be to air, cold, and inanimate surface; ordinary venesection being the only operation performed on the person who emits the blood; and the insertion of a small tube into the vein usually laid open in bleeding, being all the operation which it is necessary to execute on the person who receives it.

Although the description of the instrument must appear complex, its use is simple; in truth, when the transfusion is once begun, the operator has little to do; his principal cares are — first, to see that the cup never empties itself entirely, otherwise air might be carried down along with the blood. Secondly, to make sure that blood which issues by dribbling, from the arm of the person who supplies it, may not be admitted into the receiver, as its fitness for use is doubtful. Thirdly, to watch the accumulation of blood in the receiver and to prevent its rise above the prescribed level. Lastly, to observe with attention the countenance of the patient, and to guard against an overcharge of the heart. This latter cause is of great importance.

In this account, we find many elements familiar to modern transfusion medicine: the careful harvesting of blood from the donor, a slow infusion process, the risk of air embolism and worries over volume overload. Blundell's advances were revolutionary in their day, but no event did more to promote IV therapy than the outbreaks of cholera throughout Europe in the second third of the nineteenth century.

THE STORY OF CHOLERA

The years between 1831 and 1832 were frightening times to live in London or Paris. A supposedly 'tropical disease' had invaded the great northern cities with devastating effect (12). Cholera killed its victims within hours of the first

symptom, and physicians were utterly helpless to treat, prevent or even explain it. Cholera, we now know, is always linked to human excreta and the lack of appropriate toilets. In the 1830's Europe was undergoing the most rapid urbanization in its history due to industrialization. Marx was pinning his first stirrings against the dehumanizing changes. It was common for up to forty urban families to share one water closet and even those with these 'toilets' were in the habit of 'depositing their excreta in a newspaper, folding it up and throwing it with its contents out of a back window' (19, 45). Even when excreta made its way into the sewers, it often flowed back into the homes from which it had come. The *Times of London* reported on October 25, 1831 that 'the main sewer, from Coventry-street to Pantonestreet, is more than two feet above the level of the basement floor, consequently the houses on both sides of the street are below the drainage (40).

Those who witnessed the cholera epidemic (20) describe the images that would stalk the narrow lanes and warrens of Europe's cities — the dreadful retching, the blue faces on gaunt, slumped skeletal forms, the endless torrents of pus and blood-stained faeces which the textbooks have sanitized into 'dysentery'. It was always the same : the loosening of the sphincters on either end, the liquefaction of the gastrointestinal tract and a pouring out. There was one thing common to all victims : total prostration ! There was no other way to face cholera but face-down. One must not force a weakened heart to pump caudally. They were all brought low, the rich with the poor, clinging to mother earth.

Doctors responded with the conventional treatments of the day : bleeding the patient, administration of brandy and laudanum (opium in alcohol) and the breathing of nitrous oxide. Needless to say, these did more harm than good. Then several weeks into the 1831 epidemic a breakthrough occurred. Dr. William Brooke O'Shaughnessy observed that a large amount of water and its saline and alkali were lost from the blood of cholera victims. In *The Lancet*, in 1832, O'Shaughnessy reported his findings (42). He was 'struck with the remarkable deficiency in the serum of the blood remaining in the body of the cholera patient. This suggested to him the practice of throwing into the blood vessels a quantity of water, with salt and albumen (the white of an egg) sufficient to supply the deficiency in the blood of these materials' (41). He deduced that the blood must be restored to its previous specific gravity. 'In those desperate cases,

the injection of tepid water with normal salts of the blood into the blood stream is indicated,' O'Shaughnessy claimed (29). Thus was born the 'normal saline' infusion.

When cholera struck the continent on March 26, 1832 Paris had 786,000 inhabitants. One of every nineteen became infected and 18,000 died by October. It struck mainly the poor. Crowded twelve to a room in the Cité and Les Halles, entire buildings were decimated in a day. It would, however, have been much worse if O'Shaughnessy's findings had not already come across the channel.

In 1832 Dr. Thomas Latta, a student of O'Shaughnessy's methods, performed the first IV procedure, giving a saline injection to a patient with 'blue' cholera. He witnessed a 'miracle' recovery from the dehydrated patient (17). He had feared he'd arrived too late to save the patient, who 'apparently had reached the last moments of her earthly existence and now nothing could injure her. Indeed, so entirely was she reduced that I feared that I should be unable to get my apparatus ready, ere she expire' (16, 43). But he made it in time and she recovered and survived. Latta went on to treat dozens of others with remarkable success.

Suddenly, as mysteriously as it had appeared, cholera faded away. For seventeen years Paris was cholera-free. And then, on March 18, 1849, the first new case was rushed to Hôtel Dieu. It was back, this time to infect one in twenty-eight of the now 1 million Parisians. By the time the epidemic had run its course in October, twenty-thousand more lay dead. Perhaps twice this many would have died had it not been for the fledgling science of IV therapy.

FLUIDS AND SOLUTIONS, NEEDLES AND SYRINGES

In 1843 Claude Bernard, a French physiologist, infused a sugar solution into dogs. For the next twenty years he experimented with various concoctions, including those containing egg whites and milk, searching for the ideal infusate to replace blood. He discovered that cane sugar, injected intravenously, appeared in the urine while ingested sugar, passing through the stomach, was not detectable, thus suggesting it had been consumed by the cells as fuel. By the 1850's Bernard and others had shown the importance of protein in maintaining good health, weight gain and nitrogen balance (5, 32). There were other advances in the arena of nutritional support in the second half of the nineteenth century. Menzel and Perco, Austrian researchers, suggested, in 1869, that infused fat,



Fig. 4. — A Pravaz-type syringe, made of glass and silver

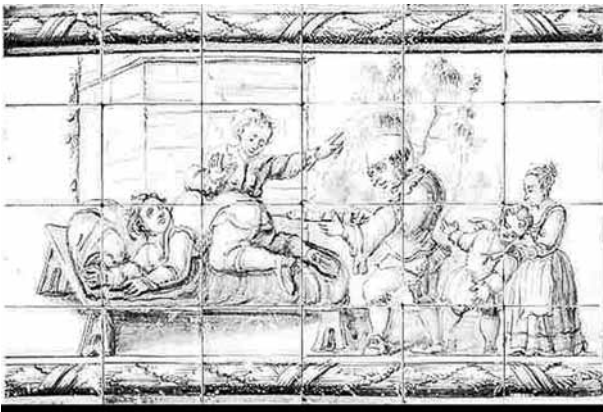


Fig. 5. — Sixteenth century painting on Portuguese tiles (azulejos) depicting an enema injection with a 'syringe-like' device.

Courtesy of Museu de Azulejos, Lisbon, Portugal.

milk and camphor provided the ideal support (16). Dr. Hodder, from Canada, used cow's milk to correct losses from cholera; (32) and Krug, in 1878 used oil and protein extract to treat a patient with anorexia nervosa. Cow's milk was also added for volume expansion and nutritional support (9, 16).

IV treatment as we know it today would not have been possible without the development of needles and syringes. In 1845 the hollow needle was perfected by Francis Rynd (1801-1861) of Dublin. He used his device to inject morphine into nerves for the treatment of trigeminal neuralgia. In 1853, Charles Pravaz, a French doctor, developed the first practical metal syringe (Fig. 4), and in 1855, Dr Alexander Wood of Edinburgh was the first physician to use a hypodermic syringe for routine injection of narcotics into patients. The Pravaz-type syringe is made of glass and silver, although earlier syringe-like devices are seen in figures painted on ceramic tiles (known as *azulejos*) from sixteenth century Portugal (Fig. 5).

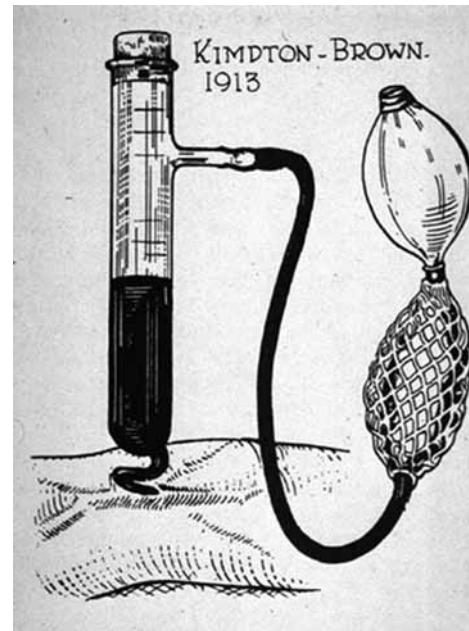


Fig. 6. — The Kimpton-Brown transfusion apparatus was commonly used before citration. It consisted of a paraffin-coated gradient glass cylinder with a horizontal side tube for suction. It was in use until approximately 1918.

PHYSIOLOGIC SALINE AND RINGERS

In 1876, Dr. Sidney Ringer proposed a physiologic solution for perfusion consisting of sodium, potassium, chloride and calcium. At first his solution was used in physiology laboratories for bathing excised frog hearts. Based on this ingenious idea, the production of Ringer's lactate, was developed. Nearly one hundred and thirty years later Ringer's lactate continues to be one of the most widely-used infusion solutions in the world.

In 1901 the ABO blood groups were identified and the techniques of typing and cross-matching began to be elucidated. By 1908 it was known that these blood types were inherited (30). Transfusion reactions were drastically reduced through careful adherence to these principles, although coagulation during transfusion remained a problem. During World War I new devices for transfusion were developed (Fig. 6) and in 1915 Dr. Oswald Robertson introduced sodium citrate as a preserved anticoagulant in transfused blood (9).

After the war, in 1933, the Baxter Travenol Company marketed the first IV solutions in vacuum bottles. Such devices greatly reduced the risk of microbial growth and pyrogens. Since that time and in many countries, a 'Baxter' has been synonymous for an IV set-up. At that time rubber tubing was used to administer the solutions, but by the

1950's plastic tubing had replaced rubber and in 1970 plastic bags were introduced, thus reducing the risk of air embolism from the air venting in glass bottles (29).

MODERN IV CATHETERS

The mid-twentieth century was the golden age for the development of disposable medical devices. In the years after the Second World War polymer chemists were finding new compounds almost weekly, engineers were making the equipment for extrusion and injection moulding of plastics, ETO sterilization was proven effective and non-harmful to plastics, physicians were improving patient care by using more invasive procedures and entrepreneurs were eager to support commercial ventures with promising new devices.

Until and even into the 1950's IV sets consisted of steel reusable needles with a stylet inside to keep the lumen open. Many physicians will still remember holding these needles up to the light to detect barbs and filing them down by hand. Then, seemingly out of the blue, the plastic revolution arrived.

It began in 1950 with a landmark discovery at the Mayo Clinic by Dr. David Massa, a resident in anaesthesiology. Massa began by shortening a 16-gauge Becton Dickinson (Franklin Lakes, NJ) needle (11) and inserting another steel needle as an inner stylet. It looked much like today's epidural needle, complete with stylet. Then, over the top of the needle was fitted a polyvinyl chloride (PVC) catheter, which was attached to a metal hub via a crimp band. The tip of the catheter was hardened and shrunk to fit the needle, using ethyl acetate which deplasticized the PVC. This resulted in an 'over-the-needle' configuration, which after several further iterations became the famous 'Rochester plastic needle'. The entire unit measured 5 mm (2 inches) and was available only in the 16-gauge size.

Here, at last, was a catheter which could be directly threaded into a vessel after venipuncture with a needle (2). The new catheter was first tried in clinical use by a Dr. Lindy at Mayo's. It provoked an instant revolution in medicine and spurred others onto greater heights.

In 1957 Deseret, a pharmaceutical company based in the deserts of Utah, was approached by a Dr. Doherty, who had just invented and patented an alternative catheter concept, a through-the-needle device. Deseret began to market this catheter made

of plasticized PVC, available in both radiopaque and non-radiopaque materials, individually packaged and ETO-sterilized. It was the first catheter in history to be individually-packaged and sterilized. Later a needle guard was added and it became the Intracath™ (Becton Dickinson, Sandy, Utah). Still, it remained a re-usable device.

In 1964 Deseret introduced the Angiocath™, the first disposable device. It was constructed of PVC, used a hypodermic-style needle and a flashback chamber and flow control plug, features not found on the Rochester needle. Prior to the advent of the flashback chamber the cannula's position *in situ* could only be verified by observing blood flowing through the hub of the inner needle when the stylet was removed.

Plastic syringes and disposable needles were introduced in a massive way to the American and European markets by Becton Dickinson, Jelco (a division of Johnson & Johnson), Deseret and other manufacturers in the early 1960s (26). Both the over-the-needle and through-the-needle concepts underwent continuous improvements and slowly replaced the cut-down devices.

With the advent of TFE Teflon tubing in 1969, the 'stickiness' of the cannula was dramatically reduced. Teflon cannulae were easy to slide over the needle and thus easy to thread into veins. They proved not only simple to insert but resistant to 'peelback' (the tendency of the thin cannula tip to roll outwards when it met resistance). Teflon was revolutionary, at the time, since it was a self-lubricating, flexible material which was also non-compliant to pressure. Teflon was also non-toxic, tissue compatible and tough.

In 1974 a precision machine-tipped catheter, the first of its kind, was developed in order to provide enhanced patient comfort. The first polyurethane over-the-needle catheter was introduced in 1983. Polyurethane proved to be less traumatic to veins, decreasing the rate of phlebitis as well as the incidence of blood clotting in the catheter lumens.

In the 1970's and 80's doctors around the world came to expect IV catheters to perform to extremely high standards, and their use became virtually universal. During this time another quiet revolution occurred. The procedure of IV cannulation shifted from being a doctor-dominated one to being nurse-dominated. Massachusetts General Hospital of Boston was the first to allow a nurse, Ada Plumer, to administer IV therapy. She became the first IV nurse and formed the first IV team (34). In 1973 the Intravenous Nurses Society was founded



Fig. 7. — Examples of ported (top) and non-port (bottom) peripheral IV catheters.

in order to promote the speciality within the nursing profession as well as to set guidelines for its practice (2, 9, 11, 23, 28, 37).

Since that time there has been continuous improvement in the development of IV catheters, resulting in both ported and non-port versions (Fig. 7). Recent innovations include notched catheters which allow for immediate flashback visualization, water-borne silicone lubricants which are more bio-compatible, safety features to decrease HIV and hepatitis risks to users (Fig. 8) and more environmentally-friendly manufacturing methods (e.g. elimination of chlorofluorocarbons and the substitution of irradiation for ETO as a sterilizer). With fully-automated catheter assembly lines, it is now possible to make low-cost catheters that are affordable in both the developed and developing world.

BASIC MECHANICS OF PERIPHERAL CATHETERS

A wide range of catheter gauge sizes are now available (Table 1) Gauge is the external diameter of the intravascular part of a catheter and is regu-



Fig. 8. — An integrated safety IV catheter

lated by an international standard (ISO 10555-5). Gauge size, abbreviated G, is denoted by a number ; the smaller the number the larger the catheter. For example an 18 gauge catheter (18G) has a larger diameter than a 24 gauge one (24G). An easier way to understand the concept of gauge is to visualize a cylinder 25 mm (1 inch) wide and to ask oneself how many needles would fit into it. Obviously the smaller the diameter of the needle the more will fit, and the larger the diameter, the fewer. In fact, twenty-four thin paediatric needles will fit in such a cylinder, and therefore they are called 24 gauge (24G). Only eighteen of the larger 18-gauge needles will fit in, hence their name, 18G. Each gauge size is identified by a standard colour, as required by ISO 10555-5 ; these are listed in Fig. 9.

The flow rate is primarily dependant on the gauge of the catheter and to a lesser extent on its length. The flow rates are stated on the back of the catheter packaging in L/hour and a non-exhaustive listing by gauge size and manufacturer is provided in Figure 9. But it must be kept in mind that these are ideal flow rates, as determined by in-vitro gravity studies using water or saline. In-vivo flow rates are invariably slower because of the resistance in veins (the main factor regulating IV pressure) and the viscosity of many of the infusates. Studies have shown that the resistance offered by fluid in veins is highly variable, but is not affected by site of catheter insertion, tissue type at insertion site, age, sex, patient anxiety, American Society of Anesthesiologists physical status or catheter size (35). The resistance in the tissues surrounding the veins is nearly always greater than that in the vein, therefore for extravasations to take place some downstream increase in resistance (e.g. thrombosis, reflux, vascular congestion or oedema) must occur (36).

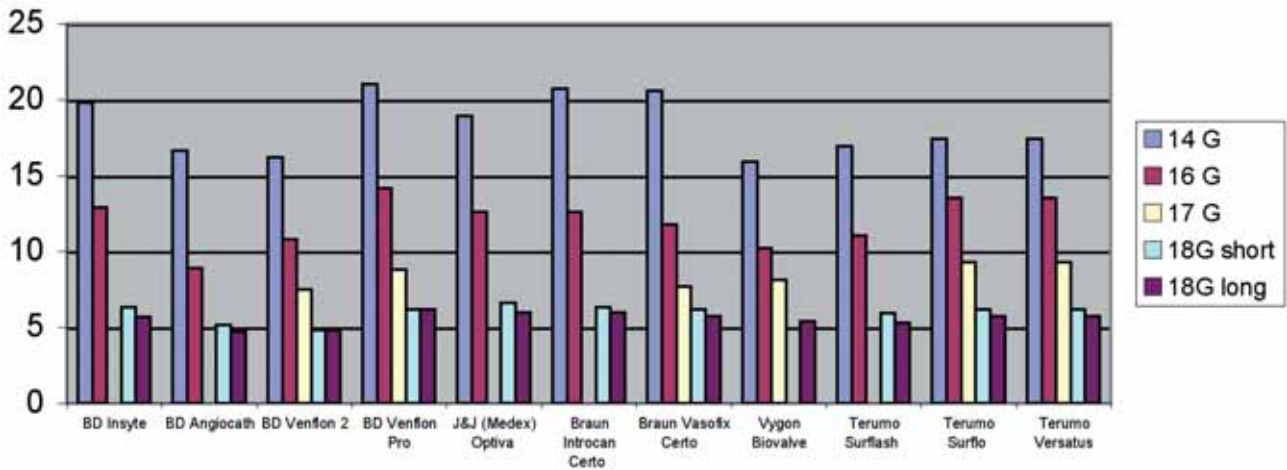


Fig. 9. — Flow rates (L/hour) as reported by manufactures for various catheters

Table 1

Recommendations by different organizations on the use of specific catheter gauges

Size Gauge	INS Recommendations (5)	UK Recommendations (2)	BD Recommendations (3)
12G 13G	*	Major resuscitative procedures requiring rapid transfusions ; mainly used in theatres	
14G		High volume transfusions ; mainly in operative procedures	Used in theatres or emergency for rapid transfusion of blood or viscous fluids
16G	Trauma patients Surgery patients Blood transfusion	High volume transfusions ; mainly in operative procedures	Used in theatres or emergency for rapid transfusion of blood or viscous fluids
17G		IV fluid therapy and blood transfusions	Blood transfusions, rapid infusion of large volumes of viscous liquids
18G	Trauma patients Surgery patients Blood transfusion	IV fluid therapy and blood transfusions	Blood transfusions, parenteral nutrition, stem cell harvesting and cell separation, large volumes of fluids
20G	Continuous infusions Intermittent infusions Blood transfusion	Blood transfusions, medication and IV fluid therapy	Blood transfusions, large volumes of fluids
22G	General infusions Intermittent infusions Blood transfusion Children and elderly	Medication ; Paediatric patients	Blood transfusions, most medications and fluids
24G	Fragile-veined patients Children General infusions Intermittent infusions	Medication ; Paediatric patients	Medications, short term infusions, fragile veins, children
24G(N)			Neonatal

* spaces left blank are not addressed in respective organization's recommendations.

INH = Intravenous Nurses Society ; UK = United Kingdom Expert Panel ; BD = Becton Dickinson.

The various materials used to manufacture catheters include Teflon, polytetrafluoroethylene, polypropylene and polyurethane. Each new material represents an advance over its predecessors and addresses a specific clinical challenge. For example, polyurethane has been shown to improve

catheter performance in ways which suggest that it may be clinically advantageous and lead to longer indwell times.

Catheter plastics have been improved to address many clinical challenges, including thrombogenicity. Some, such as polyurethane, are

designed to be rigid at room-temperature and to become more flexible after insertion, thus decreasing irritation to vein walls and reducing phlebitis. Various manufacturers have even experimented with bacteriostatic coatings on their catheters to prevent colonization and infection. In this moving-target industry, it is still possible to frame the parameters which will constitute the ideal peripheral catheter.

CHARACTERISTICS OF AN OPTIMAL PERIPHERAL IV CATHETER

The complications of peripheral IV catheters include phlebitis, frank infection and occasionally sepsis, thrombosis and haematoma at the puncture site as well as infiltration, extravasations and rarely necrosis of tissue. Today's catheters are designed to prevent many of these complications. A peripheral catheter is usually less than or equal to 7.5 cm in length, uses stainless steel needles and a plastic cannulae, is limited to short-term or single-dose administration and should deliver therapy into peripheral veins without causing infection, leakage or extravasations (1) (Fig. 7). An ideal catheter additionally provides protection to the user against sharps injury and has advanced engineering to ensure ease of use (clear flashback and visibility, flexible access and easy maintenance) and safety and comfort for the patient (Fig. 8). It should ideally provide :

Rapid reliable blood flashback. The earlier one sees blood flash back after penetrating the vein, the more likely one is to stop advancing and the less likely to traverse the opposite wall of the vein (transfixation). The earliest flashback is currently provided by notched needles. Some experimental needles use magnifiers at the flashback chamber or hub.

Clear visibility of puncture site. This feature allows the user to detect bleeding around the catheter as well as observe for the inflammatory changes that signal phlebitis or infection. Clear visibility is provided by transparent catheter components at the patient end (e.g. transparent wings) as well as a transparent dressing.

Reduced pain to patient. This is a function of many factors including the sharpness and geometry of the needle tip, the gauge of the catheter, the nature of the plastic in the catheter, the skill and speed of the inserter and his/her skill at preparing and distracting the patient.

Minimal infection risk. This is also multifactorial, depending on the catheter material, the agent and procedure used to prepare the skin, the post-insertion site care and the sterility of infusions given.

Minimal thrombotic risk. This depends on many of the same factors as the infection risk.

Dynamic softening of the catheter in the vein. Some catheter materials change their stiffness after a length of time at body temperature (i.e. inside the vein); such catheters are less likely to cause mechanical phlebitis or to kink and obstruct; they may also have a lower infection and thrombosis risk (15, 18, 25, 28, 38); however it is more difficult to draw blood back through such a catheter (not a recommended procedure due to the high potential for creating haemolysis, but, unfortunately, one often performed).

Minimal blood exposure for the user. Catheters which protect the tip after use, preferably passively as an integral function of the procedure, provide an additional measure of safety to the user. These safety-engineered devices are more costly but probably more than pay for themselves in preventing needle-stick injuries. Catheters that prevent the escape of blood into the environment provide protection against muco-cutaneous exposure of blood to the user.

Multi-lumen port access. Such catheters, when used peripherally, provide many of the advantages of a central venous catheter. Multiple ports can be provided by included an additional port on the catheter itself (the 'ported' catheters used frequently in Europe), by the attachment of a stop-cock or by the use of extension tubing (either attached or integral to the catheter) with multiple ports.

Needleless access to ports. Such catheter systems are more 'closed' to bacterial entry than conventional ones and reduce needlestick risk.

Simple to dress, difficult to snag. The optimal catheter has a flat profile allowing the dressing to cover it smoothly without wrinkling or binding up; such covering is less likely to catch on objects in the environment or to come loose between dressings.

CONCLUSION

Sir Christopher Wren, Dr. Richard Lower and their contemporaries used feather quills and animal bladders to usher in the era of IV infusion. These crude devices were replaced, in the nineteenth

century, by metal needles, rubber tubing and glass containers. Such equipment required cleaning and sterilization between uses, but it paved the way for the infusion of blood, physiologic solutions and nutritional supports. In the twentieth century equipment began to be made of plastics, first polyvinyl chloride, then Teflon and finally, polyurethane.

In 1950 a seminal event occurred with the invention of the Rochester needle by Massa. This revolutionary concept led eventually to 'over-the-needle' catheters, which are used to deliver almost all IV therapy worldwide today. The addition of filters, pumps, electronic infusion devices, drop-counters, alarms, and most recently, safety features that protect against needlestick injury and blood exposure have continued to revolutionize IV therapy and medicine in general. Most of the advances we count on today such as the detection of small lesions by MRI and PET scans, the delivery of pharmaceutical and nutritional therapy and the use of disease-specific treatments would not be possible without the simple plastic tubes that have evolved into their present state of sophistication over the last five hundred years.

Medicine will now move into 'smarter', more integrated, more closed IV systems, where drugs and fluids enter the patient's veins but germs cannot, where blood comes out only when the health care provider decides it should and where patient and user safety and comfort are paramount. Ambrose Paré would have quite a story for his colleagues when he returned to the 16th century.

Acknowledgements

The authors would like to thank Henry Alessi, Jr. of Franklin Lakes, NJ along with Chris McDown and Cal Alexander of Sandy, Utah for their invaluable contributions on the recent history of the IV catheter.

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