Chapter 9

Supporting technologies

9.6 Central venous catheter

9.6.1 History

The development of intravascular catheters and the techniques for inserting them has resulted in important advances both diagnostically (angiography) and therapeutically (CVP & Hickman lines; angioplasty).

Werner Forssmann

In the 1920s Werner Forssmann (1904–1979), then a surgical resident, was looking for safer ways of delivering cardio-active drugs to the heart (i.e., other than via direct needle injection), and eventually he hit upon the idea of using a long IV catheter. In 1929, when he was only 26, Forssmann tested this idea in a Berlin hospital, by inserting a long urinary catheter via the antecubital fossa into his own right atrium and confirmed its intra-cardiac position radiologically. He went on to use this method for injecting intra-cardiac contrast in animals, paving the way for diagnostic cardiac angiography, for which he was awarded the Nobel Prize in 1956, together with Cournand (1895–1988) & Richards (1895–1973). The following translation of part of Fossmann’s original article (Forssmann, 1929) is by Luft (1994).

In cases of shock, such as those engendered by sudden cardiac standstill, or during anesthetic emergencies and poisonings, it may be desirable to deliver medications directly to the heart itself. … Nevertheless intracardiac puncture is a dangerous procedure for several reasons, including injury to the coronary arteries and its branches, pericardial tamponade, injury to the diaphragm, and pneumothorax. … For these reasons I considered a new method to approach the heart in a less dangerous fashion, namely the catheterisation of the right heart from the venous system.

Experiments on a cadaver were productive. I was able to catheterize any vein in the antecubital fossa and was able to regularly reach the right ventricle. … I next undertook experiments on a living subject, namely on myself. I first convinced a colleague to puncture a vein in my right antecubital fossa with a large needle. I next advanced a well-oiled ureteral catheter size 4 Charriere in diameter through the needle into the vein. The catheter allowed itself to be advanced with trivial ease to 35 cm. Because my friend objected to our proceeding with these experiments further, we broke them off even though I felt perfectly well. One week later I tried

again alone. I anesthetized my own left antecubital fossa and because I was not able to manipulate the needle by myself I constructed a “cut-down” and advanced the catheter along its full 65 cm length. From surface estimates, I reasoned that the catheter tip would be at the level of the heart.

I documented the position of the catheter with roentgenograms that I obtained by standing in front of the fluoroscope while observing the catheter in a mirror held by a nurse. In conclusion, I would like to point out the utility of this technique in providing new opportunities to research the metabolic activities and actions of the heart.

Forssmann (1929) [From: Luft (1994)]

André Cournand and Dickinson Richards

Cournand and Richards extended Forssmann’s intravascular catheter concept and developed long single and double-lumen catheters which allowed them to sample blood and pressures from the right heart and pulmonary artery (c. 1940s). They also determined approximate left atrial pressures by wedging the catheters by pushing them as far as they would go (i.e., not balloon-occlusion wedge pressures as determined by Swan and Ganz in 1967). They studied cardio-pulmonary physiology and patho-physiology, and showed that hypoxia, sufficient to make the arterial oxygen saturation less than 80%, resulted in significant pulmonary vasoconstriction and a rise in pulmonary artery pressure (Cournand 1956; Richards 1956). Interestingly, they also showed that an infusion of acetylcholine (0.5 mg/min) into the pulmonary artery reversed the pulmonary vasoconstriction while not affecting the systemic blood pressure (Harris et al. 1956; Cournand 1956).

Sven-Ivar Seldinger

Radiologists often need to insert long large-diameter catheters into arteries in order to inject contrast into distant vessels. In the early 1950s, however, the two existing techniques had significant shortcomings. For example, the catheter-through-needle technique was associated with a significant leak at the vessel entry point (catheter smaller than needle), and the long narrow catheters made it difficult to inject contrast fast enough to be effective. The catheter-over-needle technique was only feasible with quite short catheters (since the needle did not bend, and long needles were difficult to manipulate safely).

In 1952 Sven-Ivar Seldinger (1921–1998) a Swedish radiologist at the Karolinska Hospital, Stockholm overcame these difficulties by developing his catheter-over-guidewire technique (Seldinger 1953; Seldinger 1987; Higgs et al. 2005; Greitz 1999). He actually used a guidewire with a straight flexible tip. Seldinger described the process of development as follows.

However, rightly or not, some people considered the procedure [translumbar aortography] hazardous and searched for a technique where a catheter could be inserted via a peripheral artery. Surgical cut down methods had been reported . . . and Bierman et al. (1951) . . . suggested a percutaneous technique in which a catheter was inserted through a puncture instrument into the femoral artery and advanced to the aorta. The catheter had to be wide enough to permit a very rapid injection. If not, the contrast medium would be so diluted by the voluminous aortic bloodflow that diagnostic angiographs would not be obtained. In turn a very wide-bore puncture instrument, with consequent risk of trauma, was required.

Thus there was obviously a need for an improved percutaneous method for aortography, and one of the requirements to the solution was an increased bore of the catheter. . . . There existed a “puncture equipment” named after Cournand, consisting of an inner sharp needle in an outer blunt cannula, the edge exceeding the cannula by one or two mm. One alternative was to use a flexible catheter instead
of the cannula, but it would certainly be tricky to handle an inner needle, half a
meter or more long. I avoided this trouble by cutting a side hole on a polythene
catheter at such a level that a cutting needle of convenient length, when inserted
through it, exceeded the tip of the catheter by one or two mm. After some moulding
of the catheter and a minute incision in the skin, this instrument could be inserted
into the artery by percutaneous puncture.

Some obvious disadvantages were inherent in this technique. For instance, the
thin-walled catheters were so flexible that, sometimes it was impossible to advance
them further into the vessel. This difficulty could often be overcome. When
intravascular position was obtained, the needle could be withdrawn from the side
hole and replaced by a semi-flexible metal wire which was introduced through the
entire length of the catheter to support it.

Now! After an unsuccessful attempt to use this technique I found myself, disap-
pointed and sad, with three objects in my hand—a needle, a wire and a catheter—
and, in a split second, I realised in what sequence I should use them: needle in—wire
in—needle off—catheter on wire—catheter in—catheter advance—wire off.

I have been asked how this idea turned up and I can quote Phokion,2 the Greek: “I
had a severe attack of common sense.”

The tools could not be less complicated; they could be found among the instruments
of any hospital and, if necessary, could be completed at the nearest ironmonger’s.
Any handy person could use them.

With the ‘beginner’s luck’ the first angiography performed with this technique
was a success: a subclavian arteriography, with one single exposure, the catheter
introduced through the brachial artery after puncture at the cubital level, which
revealed a parathyroid adenoma, unsuccessfully searched for by the surgeon in the
mediastinum,

With my permission, the Head of the Department, Knut Lindblom, reported on the
technique at the Radiological Congress of Northern Europe which took place in
Helsinki one week later, in June 1952.

Seldinger (1987)

The January 1984 issue of the American Journal of Roentgenology (volume 142) celebrated the
30th anniversary of the Seldinger Technique with a series of articles on Seldinger.3 The article
by Doby (1984) gives an excellent historical overview, and includes some detailed sketches by
Seldinger himself relating to his development of the technique.

Stanley Baum and Herbert Abrams

A not uncommon problem associated with the straight guidewire, particularly when cannulating
the femoral artery, was failure to advance easily. This problem was largely overcome in 1964 by
Baum and Abrams’ development of the J-tipped catheter which is threaded over the guidewire
(Baum and Abrams 1964). Once the catheter has been positioned above the obstruction then the
catheter is changed (by reinserting the guidewire) for a special angiography catheter.

Charles Dotter

At approximately the same time the American radiologist Charles Dotter (1920–1985), widely
regarded as the father of interventional radiology, was beginning to lay the foundations of this new
specialty at the Oregon Health State University,4 in conjunction with his student Melvin Judkins.

In 1963 Dotter inadvertently unblocked an occluded right iliac artery while passing a catheter
through it in order to reach the aorta for an abdominal aortogram, and realised that intravascular

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3See their web site at http://www.ajronline.org/ Most are are on the thoracic anaesthesia CD.
4see http://www.ptca.org/no/history.html, and also http://www.ohsu.edu/dotter/
catheterisation can be used therapeutically as well as diagnostically. On 16 January 1964, Dotter, together with Judkins, performed the first deliberate dilation of an arterial obstruction, and thereafter developed the tools and techniques for what is now known as transluminal angioplasty (Payne 2001). Dotter also developed the first safety J-tipped guidewire (Judkins et al. 1967), flow-guided catheter, an intravascular biopsy catheter, and intravascular coils which were the forerunner of expandable stents (http://www.ohsu.edu/dotter/ctdotter.htm).

### PICC catheters—Broviac JW and Hickman

With the advent of intensive care, intravenous nutrition and chemotherapy central catheters were increasingly used for long periods of time, leading to significant catheter-related infections. This prompted engineers to address design and materials issues, leading to new long-term so-called PICC catheters, first by Broviac et al. (1973) and later by Hickman et al. (1979). Special valved catheters (Croshong catheter) were developed by Bard Access Systems.

- Courmand AF (1956). Control of the pulmonary circulation in man with some remarks on methodology. (Nobel Lecture)
- Richards DW (1956). The contribution of right heart catheterization to physiology and medicine, with some observations on the pathophysiology of pulmonary heart disease. (Nobel Lecture)

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5PICC — Peripherally Inserted Central Catheter.
9.6.2 Optimum position

The current view regarding the optimum location of the tip of a CVP-catheter is driven by the need to avoid the possibility of the catheter migrating into the pericardium. Consequently the tip should be above the pericardial reflection on to the SVC (Chalkiadis and Goucke 1998), which is generally held to be at the level of the carina (T4–T5; sternal angle)—i.e., above the left and right atria. Ryu et al. (2007) give a simple landmark-based method for safely positioning the tip of the CVP line in relation to the carina. Several articles have appeared recently describing the use of ultrasound to facilitate CVP-line placement, including a good editorial by Scott (2004).

Techniques for correcting/relocating subclavian and internal-jugular catheters which have taken an aberrant course are addressed by Pattnaik and Bodra (1999); they highlight an article by Kayal et al. (1989) who used ultrasound while flushing with saline to detect when the tip of the catheter is in the correct vessel. Pattnaik and Bodra (1999) suggest listening with a stethoscope is useful. An alternative approach to the ‘aberrant catheter’ problem, might be to consider placing a new J-wire into the same vein via the proximal lumen (hopefully in the internal jugular vein), removing the misplaced CVP line and then railroading a new one—with luck the new wire will be in a better location (one could check the new wire position with an x-ray first perhaps).

Occasionally a CVP line inserted via the left IJ vein will go down the left internal mammary vein; quite how this happens is not clear since the curved tip of the J-wire should prevent the wire from going down a small vessel. The distal lumen in such cases is typically associated with difficult aspiration and poor CVP waveform. Since redirecting a misplaced CVP line can be difficult, consider monitoring the CVP via one of the more proximal lumens—withdrawing the line slightly if necessary—until you see a good CVP waveform. Consequently, always X-ray a left IJ line before considering railroading a Swan-sheath over it. For information and video clips relating to CVP insertion technique see the Clinical Cases web-site (http://clinicalcases.blogspot.com).

9.6.3 Anatomy

  [gives a useful table of depth and diameter of the vein for various amounts of head tilt. My own working of their data gives the mean depth of the middle of the vein as 1·64 cm, which is equivalent to a distance of 2·3 cm at 45 degrees to the skin]

6I have not tried this as yet, but it seems as though it ought to work.


• Sulek CA, Gravenstein N, Blackshear RH and Weis L (1996). Head rotation during internal jugular vein cannulation and the risk of carotid artery puncture. *Anesthesia and Analgesia;* 82, 125–128. [keeping the head in the midline position reduces the incidence of carotid artery puncture]

### 9.6.4 Position of CVP tip


• Chalkiadis GA and Goucke CR (1998). Depth of central venous catheter insertion in adults: an audit and assessment of a technique to improve tip position. *Anaesthesia and Intensive Care*; 26, 61–66. [they used the subclavian method—their tailored technique (8 cm distal from the tip of needle) gave a mean distance from the skin of 13.2 cm (range: 11.5–15 cms; n=73)]


### 9.6.5 General

• Chalkiadis GA and Goucke CR (1998). Depth of central venous catheter insertion in adults: an audit and assessment of a technique to improve tip position. *Anaesthesia and Intensive Care*; 26, 61–66. [they used the subclavian method—their tailored technique (8 cm distal from the tip of needle) gave a mean distance from the skin of 13.2 cm (range: 11.5–15 cms; n=73)]


• Kitagawa N et al. (2004). Proper shoulder position for subclavian venepuncture. *Anesthesiology;* 101, 1306–1312. [evidence from CT studies suggests that best position is with the shoulder pushed inferiorly]


• Nandwani N, Fairfield MC, Krarup K and Thompson J (1997). The effect of laryngeal mask airway insertion on the position of the internal jugular vein. *Anaesthesia;* 52, 77–83. [no lateral movement, but perhaps some slight anterior movement 0.6–1.1 cm, mean 0.8 cm]


• Pattnaik SK and Bodra R (1999). Another ‘whoosh’ test. *Anaesthesia; 54*, 1224–1225. [they describe gradually withdrawing the the malpositioned central line while listening for the disappearance of the distal ‘whoosh’ sound (caused by flushing it with saline) with a stethoscope over the vein. Also list other useful references on this theme (6 refs)].


• Stickel BR and McFarlane H (1997). Prediction of a small internal jugular vein by external jugular vein diameter. *Anaesthesia, 52*, 220–222. [if the external jugular vein is greater than 7 mm diam, then the internal jugular vein is likely to have a diameter less than 7 mm, and so may be difficult to find]


### 9.6.6 Ultrasound guided


• Hall AP and Russell WC (2005). Towards safer central venous access: ultrasound guidance and sound advice. *Anaesthesia; 60*, 1–4. [see also correspondence from Reavley P (2005)]

• Habib FA and McKenney MG (2004). Surgeon-performed ultrasound in the ICU setting. *Surgical Clinics of North America; 84*, 1151–1179. [see section on CVP line placement 1165–1166, with screen images]


9.6.7 External jugular vein

If the external jugular vein distends on head-down position, then a Venflon in this site adequately reflects CVP providing the chest is not open. Placing a central catheter via this route has a high failure rate.


9.6.8 Axillary vein


9.6.9 Femoral vein

There are many papers in the literature showing that CVP is accurately reflected by inferior vena cava and common iliac venous pressure measurements in supine patients (both adult and paediatric), providing the transducer is zeroed at the usual right-atrial level on the mid-axillary line. Measurements of inferior vena cava pressures seem to be approximately 0.5 mm Hg lower than superior vena cava pressures on average, and rarely more than 3 mm Hg different, even in patients with high PEEP or raised mean airway pressures (Desmond 2003). Femoral CVP results may be less accurate in patients with significantly raised intra-abdominal pressure [the references below are from Desmond (2003)].

- Desmond J (2003). Is the central venous pressure reading equally reliable if the central line is inserted via the femoral vein? http://www.bestbets.org/ [critical care section]

I thank Dr Mofolashade Enebeli-Cliffe for drawing my attention to many of these references.


### 9.6.10 Complications

These are mostly related to air embolism, vessel damage from needle or dilator or kinked guide-wire, introducing the guide-wire outside the vessel, catheter knotting, dysrhythmias, pneumothorax and cardiac tamponade. Unusual anatomy and failure to use ultrasound visualisation appear to be prominent factors in many complications (see Section 9.6.3).

#### Guide-wire problems

The guide-wire is easily kinked, and once kinked it can not be straightened and can easily damage/tear the vein if introduced into it. A simple test to check for such kinking while trying to advance the dilator (over the wire) is to intermittently check that you can slide the wire back and forth (say, ±1 cm or so) inside the introducer. Any difficulty in sliding the wire back and forth is a good sign that the wire may have become kinked.

In my experience, the guide-wire is most easily damaged/kinked when using the femoral approach in fat patients. The kinking of the guide-wire usually occurs while trying to introduce the dilator through the subcutaneous tissue, since in fat patients the path of the guide-wire here becomes quite curved once the Sonosite probe is removed. Consequently, it may be preferable to replace the Sonosite probe (i.e., to straighten the subcutaneous path of the guide-wire) while introducing the dilator.

If a dialysis catheter guide-wire does become kinked it is often possible to exchange it safely by first railroading an ordinary CVP line into the vein (while protecting the kink within the CVP line), replacing the damaged wire with a new guide-wire and then removing the CVP line, and continuing with the dialysis line as before.

  [a new catheter pierced an existing catheter in the same vein; interventional radiology used for diagnosis and determination of a removal strategy; the literature is reviewed; 11 refs]


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8 Persistence of the left superior vena cava (LSVC)—which is asymptomatic—is thought to be the most common anomaly of the venous circulation and can be a significant hazard with regard to CVP line placement (see paper by Schummer, Schummer and Gerald (2002) listed in Section 9.6.3).

9 Since the guide-wire is initially introduced via a straight needle while the Sonosite probe is pressing down over the vein.