Supporting technologies — arterial line

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Chapter 9

Supporting technologies

9.5 Arterial line[1]

9.5.1 History

The first direct measurement of arterial blood pressure is generally said to have been in 1733 by Stephen Hales (1677–1761) using a glass tube 9 feet long connected flexibly (using the trachea of a goose) to the femoral and carotid arteries of horses (Comroe 1977, pp. 15–17). Some eight years earlier the physician and mathematician Daniel Bernoulli (1700–1782) was measuring fluid pressure in pipes using a narrow tube (Quinney 1997). In 1828 Jean-Louis Poiseuille (1799–1869) developed this technique further (see also: Zuck 1997) using a U-tube filled with mercury to determine the pressure at various points along the aorta (his later researches into flow in small tubes led to his famous Poiseuille's Law).

The first clinically useful placement of an arterial catheter for this purpose was developed by Peterson *et al.* (1949). They described their method as follows.

> A small plastic catheter, inserted into an artery through a needle, is left in the artery when the needle is withdrawn. Attached to a capacitance manometer, this technique permits recording for long periods of time without discomfort and allows relatively free mobility of the subject.
>
> Comroe (1977), p. 36

Use of the strain-gauge (Tomlinson, 1876) for transducing arterial pressure was first described a few years earlier by Lambert and Wood (1947). See letter by Kannan (2005) for recent use of ultrasound to facilitate arterial line placement.

- Barr PO (1961). Percutaneous puncture of the radial artery with a multipurpose Teflon cannula for indwelling use. *Acta Physiol. Scand*; 51, 643.
- Comroe JH (1977). Retrospectroscope: insights into medical discovery. (Von Gehr Press, Menlo Park, California, USA).
- El-Hamamsy I, Düurrleman N, Stevens L-M, Leung TK, Theoret S, Carrier M and Perrault LP (2003). Incidence and outcome of radial artery infections following cardiac surgery. *Annals of Thoracic Surgery*; 76, 801–804. [strict systematic changing of arterial lines on a timely basis is unwarranted]
- Hales S (1733). *Statical essays: Containing haemastatics.* vol 2. (Innys and Manby, London). 361 pp.

[1] `http://www.nickalls.org/dick/papers/thoracic/hand-artline.pdf`

- Kannan S (2005). Another use for ultrasound in the ICU. *Anaesthesia*; 60, 944. [used a 7 MHz ultrasound probe; useful in oedematous patients; 7 refs]
- Peterson LH, Dripps RD and Risman G (1949). A method for recording the arterial pressure pulse and blood pressure in man. *Am. Heart J.*; 37, 771–782.
- Poiseuille JLM (1828). *Recherches sur la Force du Coeur Aortique*; Thèse No. 166 (Didot, Paris).
- Quinney DA (1997). Daniel Bernoulli and the making of the fluid equation. http://plus.maths.org.uk/issue1/bern/index.html
- Tomlinson H (1876). On the increase in resistance to the passage of an electric current produced on wires by stretching. *Proc. Soc. Exp. Biol. Med.*; 64, 186–190.
- Wong AYC and O'Regan AM (2003). Gangrene of digits associated with radial artery cannulation. *Anaesthesia*; 58, 1034–1035. [overview of rare complications, and discusses use of the 'modified' Allen test]
- Zuck D (1997). Anaesthesia and physiology: the first twenty years. *The History of Anaesthesia Society Proceedings*; 20, 75–90.

9.5.2 Anatomy

An extensive collateral network of superficial and deep palmar arches normally connects the radial and ulna arteries in the hand. However, in 58 % of patients the palmar arches are incomplete, and of these 'incomplete' cases approximately 4 % will suffer significant vascular insufficiency if the radial artery is removed or occluded (Cable, Mullany & Schaff 1999; Lippert H and Pabst R 1985) — see Allen test below.

- Coleman SS and Anson BJ (1961). Arterial patterns in the hand based upon a study of 650 specimens. *Surg. Gynecol. Obstet.*; 113, 409.
- Husum B and Palm T (1978). Arterial dominance in the hand. *Br. J. Anaesth.*; 50, 913.
- Lippert H and Pabst R (1985). *Arterial variations in man: classification and frequency.* (JF Bergmann Verlag, Munich, Germany). [cited by Cable, Mullany & Schaff 1999]
- Riekkinen HV, Karkola KO and Kankainen A (2003). The radial artery is larger than the ulna. *Annals of Thoracic Surgery*, 75, 882–884. [mean internal diameter is 3·1 mm (range: 2–4 mm)]

9.5.3 Allen test

Edgar V Allen (1900–1961) was a physician at the Mayo Clinic, and co-author of a textbook on vascular medicine (Allen, Barker and Hines 1946). He described a simple test (the so-called Allen test) to reveal ulnar or radial artery occlusion at the wrist (Allen 1929). His description with respect to the ulnar artery is as follows.

> If obstruction of the ulnar artery is suspected, the radial arteries are located by their pulsations; the examiner places one thumb lightly over each radial, with the four fingers of each hand behind the patient's wrist, thus holding the wrist lightly between the thumb and fingers. The patient closes his hands as tightly as possible for a period of 1 minute in order to squeeze the blood out of the hand; the examiner compresses each wrist between the thumb and fingers, thus occluding the radial arteries; the patient quickly extends his fingers partially while compression of the radial arteries is maintained by the examiner. The return of color to the hand and fingers is noted. In individuals with an intact arterial tree the pallor is quickly replaced by rubor of a degree higher than normal.
>
> Cable, Mullany & Schaff (1999)

Before 'harvesting'[2] or even cannulating the radial or ulnar artery, the adequacy of collateral vessels should be assessed by an Allen test (after EV Allen 1929), to determine if they alone can adequately supply the hand. If a vessel fails the Allen test, then the other vessel certainly should not be harvested, and probably ought not to be cannulated either.

Modified Allen test

Erroneous results can arise if the test is not performed correctly (Greenhow 1972). Note that the wrist must not be hyperextended as this can cause vessel occlusion and invalidate the test (Fuhrman *et al.* 1992). The slightly more controlled so-called 'modified' Allen test (Vaghadia *et al.* 1988) is now generally used (compressing both arteries simultaneously), in conjunction with the following 'pass' or 'fail' times.

> [both] the ulnar and radial arteries are compressed at the wrist for $\geq$ 30 secs to induce hand ischaemia, while the hand is drained of blood by tight clenching. The test vessel is then released and the time to adequate perfusion of the tips of the fingers and thumb noted. The vessel is said to pass or fail the test as follows: pass ($<$ 5 secs); equivocal (6–10 secs); fail ($>$ 10 secs)
>
> Royse *et al.* (1999)

Note that the vessels should actually be compressed just proximal to the point where the tip of the cannula is expected to lie, in order to detect essential collateral branches *distal* to the likely cannula tip position (Gandhi and Reynolds 1983). Plethysmography is more sensitive than either the Allen test or pulse-oximetry (Fuhrman *et al.* 1992).

- Allen, EV (1929). Thrombo-angiitis obliterans:[3] methods of diagnosis of chronic occlusive arterial lesions distal to the wrist, with illustrative cases. *American Journal of Medical Sciences*; 178 (August), 237–244.
- Allen, EV, Barker NW and Hines EA (1946). *Peripheral vascular diseases.* (WB Saunders Company, Philadelphia, USA). [from Wright 1952]
- Cable DG, Mullany CJ and Schaff HV (1999). The Allen test. *Annals of Thoracic Surgery*; 67, 876–877. [excellent – includes a photograph of Allen]
- Fuhrman TM, Pippin WD, Talmage LA and Reilley TE (1992). Evaluation of collateral circulation of the hand. *J. Clinical Monitoring and Computing*; 8, 28–32.
- Gandhi SK and Reynolds AC (1983). A modification of Allen's test to detect aberrant ulna collateral circulation. *Anesthesiology*; 59, 147–148.
- Glavin RJ and Jones HM (1989). Assessing collateral circulation in the hand — four methods compared. *Anaesthesia*; 44, 594–595.
- Greenhow DE (1972). Incorrect performance of Allen's test—ulnar-artery flow erroneously presumed inadequate. *Anesthesiology*; 37, 356–357.
- Paul BZS and Feeney CM (2003). Combining the modified Allen's test and pulse oximetry for evaluating ulna collateral circulation to the hand for radial artery catheterization of the ED[4] patient. *The California Journal of Emergency Medicine*; 4, 89–91.
- Royse *et al.* (1999). Radial artery harvest technique, use and functional outcome. *European J. of Cardio-thoracic Surgery*; 15, 186–193. [available for download at: `http://www.heartweb.com.au/PDFs/RAharvest.pdf`]
- Sinton I (2003). Digital ischaemia after ulnar artery cannulation. *Br. J. Anaesth.*; 91, 302–303. [letter]

[2] The radial artery is sometimes removed (known as 'harvesting') for use in coronary-artery or temporal-artery bypass procedures—see Royse *et al.* (1999).

[3] Buerger's disease.

[4] Emergency Department

- Vaghadia H, Schechter MT, Sheps SB and Jenkins LC (1988). Evaluation of a postocclusive reactive circulatory hyperaemia (PORCH) test for the assessment of ulna collateral circulation. *Can. J. Anaesth.*; 35, 591–8. [a 'modified' Allen test]

9.5.4 Systolic pressure variation

Real-time measurement of systolic-diastolic pressure variation with respect to spontaneous ventilation or with IPPV may be useful as an index of hypovolaemia, either via pulse oximetry waveform variation or via direct arterial measurement.

- Fujita Y and Sari A (2003). On-line monitoring of systolic pressure variation. *Anesthesia and Analgesia*; 96, 1529-1530.
- Reuter DA, Felbinger TW, Kilger E *et al.* (2002). Optimizing fluid therapy in mechanically ventilated patients after cardiac surgery by an on0line monitoring of left ventricular stroke volume variations: comparison with aortic systolic pressure variations. *Br. J. Anaesth.*; 88, 124–126.

9.5.5 Complications

Complications from arterial cannulation are rare, but therapeutic vasodilation in the form of stellate ganglion block (Gyanendra *et al.* 1998), or use of intra-arterial phentolamine (Burrell 1977) or papaverine is sometimes required.

- Burrell AR (1977). Treatment of ischaemia following radial artery cannulation. *Anaesthesia and Intensive Care*; 5, 388. [used intra-arterial phentolamine (diluted to 0·5 mg/ml) and gave a 3 ml bolus, followed a while later by a 5 ml bolus.].
- Gyanendra U and Kashyap L (1998). Accidental single brachial artery puncture leading to reversible ischaemia of the upper limb. *Intensive Care Medicine*; 24, 197. [severe spasm following 16-G needle puncture treated using repeated stellate ganglion block]
- Leroy O, Billiau V, Beuscart C, Santre C, Chidiac C, Ramage C and Mouton Y (1989). Nosocomial infections associated with long-term radial artery cannulation. *Intensive Care Med.*; 15, 241–246.
- Lindsay SL, Kerridge R and Collett BJ (1987). Abscess following cannulation of the radial artery. *Anaesthesia*; 42, 654–657.
- Mastan M and Van Oldenbeek C (2003). Digital ischaemia after ulnar artery cannulation. *Br. J. Anaesth.*; 90, 111. [letter]. [see reply: Sinton I (2003); 91, 302–303; uses a modified Allen test]
- Ryan DW (1989). Limitations of invasive intravascular monitoring. *Intensive Therapy and Clinical Monitoring*; 10, 216–220.
- Slogoff S, Keats AS and Arlund C (1983). On the safety of radial artery cannulation. *Anesthesiology*; 59, 42–47.
- Wilkins RG (1985). Radial artery cannulation and ischaemic damage—a review. *Anaesthesia*; 40, 896–899.