

Review

Clinical review: Complications and risk factors of peripheral arterial catheters used for haemodynamic monitoring in anaesthesia and intensive care medicine

Bernd Volker Scheer¹, Azriel Perel² and Ulrich J Pfeiffer³

¹Junior house officer, Department of General Surgery, St Mary's Hospital, Newport, Isle of Wight, UK

²Professor and Chairman, Department of Anesthesiology and Intensive Care, Sheba Medical Center, Tel Aviv University, Israel

³Senior Lecturer of Intensive Care Research, Technical University of Munich, Faculty of Medicine, Germany

Correspondence: Bernd Volker Scheer, volkerscheer@yahoo.com

Published online: 18 April 2002

Critical Care 2002, **6**:198-204

© 2002 BioMed Central Ltd (Print ISSN 1364-8535; Online ISSN 1466-609X)

Abstract

In order to evaluate the complications and risk factors associated with peripheral arterial catheters used for haemodynamic monitoring, we reviewed the literature published from 1978 to 2001. We closely examined the three most commonly used arterial cannulation sites. The reviewed papers included a total of 19,617 radial, 3899 femoral and 1989 axillary artery catheterizations. Factors that contribute to higher complication rates were investigated. Major complications occurred in fewer than 1% of the cases, and rates were similar for the radial, femoral and axillary arteries. We conclude that arterial cannulation is a safe procedure.

Keywords axillary artery, catheter, complication, femoral artery, haemodynamic monitoring, peripheral, radial artery

Indwelling arterial catheters are used routinely for continuous haemodynamic monitoring in the operating room during major surgery and in critically ill patients. Arterial cannulation provides easy and convenient access, allowing multiple blood samplings and blood gas analysis. Arterial cannulation has generally been found to be a safe procedure, with few serious complications [1–6]. Approximately 8 million and 2.5 million arterial catheters are placed yearly in the USA and Europe, respectively [7]. Despite the frequency with which arterial catheters are employed, there is little information on the impact of cannulation site on risk for complications [8]. We reviewed reports concerning arterial cannulation sites such as the radial, femoral, axillary, brachial, ulnar, dorsal pedis, tibial posterior and temporal arteries with regard to thrombotic, infectious and vascular complications.

Material and methods

The PubMed, Medline Express and Winspircs databases (publication years 1978–2001) were searched to identify pertinent articles. The keywords 'artery catheter', 'radial artery catheter', 'femoral artery catheter', 'axillary artery catheter', 'catheter complication', 'hemodynamic monitoring' and 'peripheral methods' were used. We reviewed the papers and identified further articles from the references of the papers found in the initial search.

We reviewed all studies concerning the use of radial, femoral, axillary, brachial, ulnar, dorsal pedis, tibial posterior and temporal artery catheters for haemodynamic monitoring that dealt with complications and risk factors in adults. We excluded studies conducted in the paediatric patient population.

We opted not to perform statistical analyses because the data selection of the published reports do not follow the same criteria, and most of them give no specific information regarding patient population, catheter material, cannulation technique and times. Therefore, comparison between studies and statistical analyses are unlikely to be valid.

Results

We identified 78 studies that met our criteria.

Radial artery

The radial artery is the most common site for arterial cannulation, and the studies that reported complication rates are listed in Table 1 [9–32]. The most common complication was temporary occlusion of the artery, the incidence of which ranged from 1.5% [17] to 35% [10] (mean 19.7%), the variability being due to the different methods employed and the degree of effort invested in detecting this complication.

Table 1**Complications following radial artery cannulation**

| Reference | Cases | Permanent ischaemic damage (n) | Temporary occlusion (n) | Sepsis (n) | Local infection (n) | Pseudoaneurysm (n) | Haematoma (n) | Bleeding (n) |
|--------------------|--------|--------------------------------|-------------------------|------------------|---------------------|---------------------|---------------------|-----------------|
| [9]* | 80 | 1 | 9 | 0 | 0 | – | – | – |
| [9]* | 34 | 1 | 10 | 0 | 2 | – | – | – |
| [10] | 100 | 0 | 35 | – | – | – | – | – |
| [11] | 148 | 0 | 27 | – | – | – | – | – |
| [12] | 29 | 0 | 5 | – | – | – | – | – |
| [13] | 62 | 0 | 16 | 0 | 0 | – | – | – |
| [14] | 333 | 0 | 100 | 0 | 16 | – | 29 | – |
| [15] | 40 | 0 | 2 | – | – | – | – | – |
| [16] | 100 | 2 | 14 | 0 | 1 | – | 31 | – |
| [17] | 197 | 0 | 3 | 3 | 4 | 2 | – | 1 |
| [18] | 178 | 0 | 7 | 1 | 3 | – | – | 1 |
| [5] | 1699 | 0 | 360 | 0 | 1 | – | 206 | – |
| [19] | 26 | 0 | 6 | 0 | 1 | 1 | 1 | – |
| [20] | 100 | 0 | 14 | – | – | – | – | – |
| [21] | 100 | 0 | 33 | 0 | 1 | – | 13 | – |
| [22] | 118 | 0 | 18 | 0 | 0 | – | 21 | – |
| [23] | 200 | 0 | 15 | – | – | – | 61 | – |
| [24] | 25 | 0 | 3 | 0 | 0 | – | – | – |
| [25] | 200 | 0 | 60 | 0 | 0 | – | 32 | – |
| [26] | 193 | 0 | 50 | 0 | 4 | – | – | – |
| [27] | 88 | 0 | 15 | – | – | – | – | – |
| [28] | 2900 | – | – | 4 | 12 | 5 | – | – |
| [29] | 38 | 0 | 3 | – | – | – | 5 | – |
| [30]* | 45 | 0 | 4 | – | – | – | 10 | – |
| [30]* | 44 | 0 | 11 | – | – | – | 9 | – |
| [31] | 12,500 | – | – | – | – | 6 | – | – |
| [32] | 40 | 0 | 11 | – | – | – | – | – |
| Mean incidence (%) | | 0.09 (4/4217) | 19.7 (831/4217) | 0.13 (8/6245) | 0.72 (45/6245) | 0.09 (14/15,623) | 14.40 (418/2903) | 0.53 (2/375) |

The total number of cannulations was 19,617. *One study examining two different populations. –, Not investigated.

Generally, temporary occlusion of the artery has no serious sequelae. Permanent occlusion of the radial artery appears to be rare because it was reported in only four patients (mean incidence 0.09%).

Another serious complication is pseudoaneurysm, which was reported in 14 patients (mean incidence 0.09%). Pseudoaneurysm poses a risk for infection, sepsis, rupture [33–35] and formation of an extracorporeal pseudoaneurysm [36]. Radial catheterization was associated with sepsis in eight patients (mean incidence 0.13%), whereas local infection at the cannulation site was identified in 45 patients (mean incidence 0.72%).

Minor complications such as haematoma formation or bleeding at the puncture site are also shown in Table 1. Other complications include abscess, cellulitis, paralysis of the median nerve [37–39], suppurative thrombarteritis [40], air embolism [41], compartment syndrome and carpal tunnel syndrome [42–44]. Other rarely reported complications include catheter failure as result of manufacturing defect or incorrect use with resultant catheter replacement [45–48].

Femoral artery

We identified 11 studies that used the femoral artery for haemodynamic monitoring, which are listed in Table 2 [17–19,49–56]. Temporary occlusion was reported in 10 patients (mean incidence 1.45%), and serious ischaemic complications requiring extremity amputation was reported in three patients (mean incidence 0.18%) [56].

Pseudoaneurysm formation occurred in six patients (mean incidence 0.3%), sepsis was observed in 13 patients (mean incidence 0.44%) and local infection was reported in five patients (mean incidence 0.78%). Bleeding (generally minor) was observed in five patients (mean incidence 1.58%), and haematoma formation was reported in 28 (mean incidence 6.1%). One patient developed an infected haematoma and needed blood transfusion [17] and another patient eventually died from massive retroperitoneal bleeding [57].

Axillary artery

The axillary artery was cannulated in a total of 1989 reported cases. The complication rates at this site are summarized in Table 3 [54,55,58–61]. Serious complications included

permanent ischaemic damage in two patients (mean incidence 0.20%), pseudoaneurysm formation in one patient (mean incidence 0.1%) and sepsis in five patients (mean incidence 0.51%). Paresthesia of the hand due to pressure on the brachial nerve plexus was also described [54,59].

Other sites for arterial cannulation

Other less frequently reported cannulation sites are the brachial, dorsal pedis, ulnar, tibial posterior and temporal arteries.

Only one serious complication was found in a study of 1000 patients [62] in which the brachial artery was used for invasive monitoring in ambulatory patients. This complication was an infected haematoma arising from a pseudoaneurysm. Another study that employed the brachial artery for arterial blood sampling in 6185 patients [63] also showed a small number of complications (incidence 0.2%), mainly paresthesias.

The dorsal pedis artery has also been cannulated without any major complications [24,54]. However, because of its distance from the central circulation and associated difficulties in hypotensive patients it is generally avoided [64]. The ulnar artery has been used without serious complications, and in a direct comparison [29] this site exhibited similar complication rates to those encountered with the radial artery.

The tibial posterior artery has been used in paediatric patients, without major complications [65,66]. However, there also exists a case report of limb amputation secondary to a tibial artery catheterization [67]. The temporal artery is an end artery of the external carotid artery, and is usually avoided for fear of serious complications. There is a report of three cases of cerebral embolization in paediatric patients [68].

Further studies

Other studies that examined arterial catheter complications but that did not specifically attribute their occurrence to one specific site are listed in Table 4 [49,69–71]. One study [69] used mainly the radial ($n = 210$), ulnar ($n = 158$) and dorsalis pedis arteries ($n = 82$), whereas another [49] used mainly the femoral ($n = 46$), brachial ($n = 9$), axillary ($n = 3$) and radial arteries ($n = 1$). One serious complication was found at the femoral site, with compromised circulation to the leg [70]; eventually, thrombectomy was required. Another reported serious complication is air embolism caused by improper use of the flushing device [70].

A recent study [71] examined complication rates, comparing medical with surgical intensive care units. It also directly compared radial and femoral artery catheters. There were no significant differences in terms of sepsis and local infection rates between the femoral and radial arteries, and no significant difference between the medical and surgical intensive care units.

Another nine studies specifically looked for septic complications associated with arterial catheter placement, and

included a total number of 1681 patients (Table 5) [52,54,72–78]. No septic complications were identified in seven of those studies [52,72–77], and nine cases of sepsis were reported in the remaining two studies [54,78]. All of the cases of sepsis were identified after the line had been in place for longer than 4 days. The studies in which sepsis was reported predominately used the radial artery.

Risk factors

A further objective of the present review was to consider risk factors that might have impacted on complication rates.

Thrombotic complications

Thrombus formation and occlusion of the artery appear to be caused by changes in the integrity of the vessel wall induced by the presence of the catheter [79]. Recannulation of the occluded artery generally occurs, but this may take up to 75 days [80]. The incidence of thrombus appears to be related to the degree to which the catheter fills the arterial lumen [3]. It has been shown that the incidence of radial obstruction increases linearly with the ratio of outer diameter to vessel lumen diameter [81]. This might explain the higher incidence of radial occlusion in female patients, who generally have vessels of smaller diameter [5,10,14,22,25]. This has led to a preference for 20-gauge catheters for radial artery cannulation [11,14]. Teflon catheters also appear to be associated with a lower incidence of occlusion [11], but in another study [5] this could not be confirmed. Patients with a low cardiac output have a higher incidence of radial artery occlusion [5,14], but no difference was found among patients with episodes of hypotension [21]. Multiple punctures for catheter insertion was shown to be a risk factor for complications in one study [14], but this could not be confirmed in another [5]. A higher incidence of occlusion is found in the presence of a haematoma [5,14,21]. Patients who are treated with aspirin or low-dose heparin have fewer vessel occlusions [13,14]. The age of adult patients does not appear to be a risk factor [14]. An important factor with regard to arterial occlusion is the duration of cannulation. A higher incidence of occlusion was reported when the cannula was left in place longer than 48 or 72 hours [5,9,14,16,25].

Infectious complications

Important factors in decreasing the incidence of catheter-related infections are aseptic insertion technique and adequate disinfection of the insertion site [82]. The risk for infectious complications and sepsis increases with the duration of cannulation, especially if the catheter is left in place for longer than 96 hours [78,83]. The catheter material also appears to be of importance, because Teflon has a greater resistance to *Escherichia coli* and *Pseudomonas aeruginosa* [84] and a lower affinity for staphylococci [85]. Prophylactic treatment with antibiotics does not appear to reduce the risk for catheter-related infections [78,83], but antibiotic bonding of the catheter may confer a degree of protection [86,87]. Arterial catheter placement via the cut-down technique is

Table 2**Complications following femoral artery cannulation**

| Reference | Cases | Permanent ischaemic damage (n) | Temporary occlusion (n) | Sepsis (n) | Local infection (n) | Pseudoaneurysm (n) | Haematoma (n) | Bleeding (n) |
|--------------------|-------|--------------------------------|-------------------------|-------------------|---------------------|--------------------|-----------------|-----------------|
| [49] | 46 | – | – | 0 | – | – | – | – |
| [50] | 50 | 0 | 1 | 0 | – | – | 5 | – |
| [51] | 85 | 0 | 0 | 0 | – | – | 10 | – |
| [17] | 113 | 0 | 0 | 0 | 0 | – | – | 4 |
| [52] | 89 | – | – | 0 | 0 | – | – | 1 |
| [53] | 2100 | – | – | 6 | – | 6 | – | – |
| [18] | 114 | 0 | 4 | 2 | 0 | – | – | 0 |
| [54] | 42 | 0 | 1 | 0 | 1 | – | 3 | – |
| [55] | 220 | 0 | 1 | 4 | 4 | – | 8 | – |
| [19] | 64 | 0 | 3 | 1 | 0 | – | 2 | – |
| [56] | 976 | 3 | – | – | – | – | – | – |
| Mean incidence (%) | | 0.18 (3/1664) | 1.45 (10/688) | 0.44 (13/2923) | 0.78 (5/642) | 0.3 (6/2100) | 6.1 (28/461) | 1.58 (5/316) |

The total number of cannulations was 3899. –, Not investigated.

Table 3**Complications following axillary artery cannulation**

| Reference | Cases | Permanent ischaemic damage (n) | Temporary occlusion (n) | Sepsis (n) | Local infection (n) | Pseudoaneurysm (n) | Haematoma (n) | Bleeding (n) |
|--------------------|-------|--------------------------------|-------------------------|-----------------|---------------------|--------------------|------------------|------------------|
| [58]* | 1000 | – | – | – | – | 1 | – | – |
| [58]* | 245 | 0 | 1 | 0 | – | – | – | 6 |
| [59] | 120 | 0 | 1 | 0 | 3 | – | 4 | – |
| [60] | 435 | 2 | 9 | 3 | 7 | – | 4 | 3 |
| [54] | 28 | 0 | – | 0 | 1 | – | 3 | – |
| [61] | 31 | 0 | – | 0 | – | – | 1 | 1 |
| [55] | 130 | 0 | 0 | 2 | 5 | – | 5 | – |
| Mean incidence (%) | | 0.20 (2/989) | 1.18 (11/930) | 0.51 (5/989) | 2.24 (16/713) | 0.1 (1/1000) | 2.28 (17/744) | 1.41 (10/711) |

The total number of cannulations was 1989. * One study examining two different populations. –, Not investigated.

associated with a higher risk for infection [83]. Furthermore, sepsis occurs more frequently in the presence of local site inflammation [83]. Infection may also occur through contamination by caregivers of the monitoring system, the flushing device and the infusion system [88–90].

Discussion

The use of peripheral arterial catheters for haemodynamic monitoring is widespread. The most frequently used site is the radial artery because of its well documented low complication rates and easy access [9–32]. In the present review we report on 19,617 radial artery cannulations, and the main complication was temporary occlusion of the artery (incidence 19.70%). This complication rate is close to the finding of Wilkins [91], who reviewed reports of catheterization of the radial artery with regard to ischaemic complications published between 1969 and 1983. He reported a temporary occlusion rate of 23%. In an extensive study of 1699 patients, Slogoff

and coworkers [5] reported a 21.2% rate of temporary occlusion. Although temporary occlusion is reported quite frequently, serious ischaemic damage was reported in only two studies [9,16], with a mean complication rate of 0.09%. Nevertheless, there have been reports of serious ischaemic damage after radial artery cannulation that led to necrosis, and amputation of fingers or the whole hand [92–99].

Other major complications such as pseudoaneurysm and sepsis were reported to occur in a mean of 0.09% and 0.13% of cases, respectively.

The second most cannulated artery for haemodynamic monitoring is the femoral artery, and we reviewed 3899 cases. Temporary occlusion was reported in only 1.18% of the reviewed cases. The incidence of this complication in the femoral artery is much lower than that in the radial artery. We attributed this to the larger vessel diameter of the femoral

Table 4

Studies examining arterial catheter complications without specifically attributing them to any specific site

| Reference | Cases | Air embolism (%) | Permanent occlusion (%) | Temporary occlusion (%) | Haematoma (%) | Bleeding (%) | Sepsis (%) | Abscess (%) |
|-----------|-------|------------------|-------------------------|-------------------------|---------------|--------------|------------|-------------|
| [69] | 450 | 0 | 0 | 18.4 | – | 8.7 | 0 | – |
| [49] | 59 | 0 | 1.7 | 6.8 | 5.1 | 1.7 | 0 | – |
| [70] | 506 | 0.2 | 0 | – | – | 0 | 0 | – |
| [71]* | 1556 | 0 | 0 | 3.4 | 0.2 | 1.5 | 0.06 | 0.3 |
| [71]† | 565 | 0 | 0 | 4.6 | 0.3 | 2.3 | 0 | 0.5 |

*Medical intensive care unit (radial artery 52%, femoral artery 45%). †Surgical intensive care unit (radial artery 78%, femoral artery 11%). –, Not investigated.

Table 5

Incidence of sepsis following arterial cannulation

| Reference | Cases | Sepsis (%) |
|-----------|-------|------------|
| [54] | 130 | 4 |
| [72] | 172 | 0 |
| [52] | 186 | 0 |
| [73] | 19 | 0 |
| [74] | 155 | 0 |
| [75] | 643 | 0 |
| [76] | 230 | 0 |
| [77] | 75 | 0 |
| [78] | 71 | 5.5 |

artery. Serious ischaemic complications were reported in only one study [56], and the mean complication rate was 0.18%. The incidence rates for other major complications such as pseudoaneurysm and sepsis (0.3% and 0.44%, respectively) were similar to our findings in the radial artery. Some authors caution against use of the femoral artery for cannulation for fear of higher sepsis rates because of the close proximity to the perianal region [52]. We are unable to corroborate this on the basis of the reviewed literature, and recent studies that directly compared the radial and femoral arteries with regard to septic complications identified similar rates of sepsis [53,71]. In particular, in an extensive study of 4932 patients, Frezza and Mezghebe [71] were unable to identify a difference in complication rates between the radial and femoral arteries. In that study the femoral artery was actually the preferred site in the medical intensive care unit. Other authors prefer the femoral artery over the radial artery because the femoral artery is usually palpable even in hypotensive patients and may be the only accessible route for haemodynamic monitoring [64,100–103]. The blood pressure curve that is obtained from this larger artery is generally more accurate and gives a closer estimation of the aortic blood pressure [64,100–103].

The third most cannulated artery in the present review of the literature was the axillary artery, with almost 2000 reported cases. Some authors prefer not to cannulate the axillary artery because of its close location to the carotid artery and because of fear of embolism to the brain [101]. On the basis of the data summarized here we cannot confirm this, and no case of embolism to the brain was reported. Sometimes the axillary artery is avoided because of the more difficult approach required, although (particularly in anaesthesia) it is a well known route because it requires the same approach as that for axillary nerve block [3]. The major complications encountered with the axillary artery were similar to those for the radial and femoral arteries, and we conclude that it is a safe route for arterial cannulation.

Other reviewed arteries employed for catheterization, such as the brachial, dorsal pedis, ulnar, tibial and temporal arteries, have been used without serious complications, but published reports of their use are limited.

Conclusion

Incidence rates for major complications such as permanent ischaemic damage, sepsis and pseudoaneurysm formation are low and similar for the radial, femoral and axillary arteries. They occur in fewer than 1% of cases.

On the basis of the present systematic review we can conclude that serious complications of the radial, femoral and axillary artery are rare, and that arterial cannulation is a relatively safe procedure. Nevertheless, one must be aware of the possible serious complications that might arise. Therefore, it is important to use an arterial catheter only when it is indicated and to select carefully the best cannulation site individually for each patient, because the different cannulation sites have their specific advantages and attendant risks.

Competing interests

UJP is President of Pulsion Medical Systems AG, and AP is on the medical advisory board of Pulsion Medical Systems AG, whose PiCCO product uses a femoral arterial line.

References

- Groeger JS, Strosberg MA, Halpern NA, Raphaely RC, Kaye WE, Guntupalli KK, Bertram DL, Greenbaum DM, Clemmer TP, Gallagher TJ, Nelson LD, Thompson AE, Cerra FB, Davis WR: **Descriptive analysis of critical care units in the United States.** *Crit Care Med* 1992, **20**:846-863.
- Saarela E, Kari A, Nikki P, Rauhalta V, Iisalo E, Kaukinen L: **Current practice regarding invasive monitoring in intensive care units in Finland.** *Intensive Care Med* 1991, **17**:264-271.
- Scheidegger D: **Intravascular catheters [in German].** In *Lehrbuch der Anästhesie und Intensivmedizin: Intensivmedizin.* Edited by Benzer H. Berlin: Springer Verlag; 1993:97-105.
- Wendt M, Hachenberg Th, Lawin P, Vietor G: **Electronic monitoring and data interpretation [in German].** In *Praxis der Intensivbehandlung.* Edited by Larwin P, Bruessel T, Prien T. Stuttgart, New York: Thieme; 1993:155-186.
- Slogoff S, Keats AS, Arlund C: **On the safety of radial artery cannulation.** *Anesthesiology* 1983, **59**:42-47.
- Gauer PK, Downs JB: **Complications of arterial catheterization.** *Respir Care* 1982, **27**:435-444.
- Gardner RM: **Direct arterial pressure monitoring.** *Curr Anaesth Crit Care* 1990, **1**:239-246.
- Hartung HJ: **Monitoring [in German].** In *Komplikationen in der Anästhesie.* Edited by List WF. Berlin: Springer; 1990:248-260.
- Bedford RF: **Long-term radial artery cannulation: effects on subsequent vessel function.** *Crit Care Med* 1978, **6**:64-67.
- Bedford RF: **Wrist circumference predicts the risk of radial-arterial occlusion after cannulation.** *Anesthesiology* 1978, **48**:377-378.
- Davis FM: **Radial artery cannulation: influence of catheter size and material on arterial occlusion.** *Anesth Intens Care* 1978, **6**:49-53.
- Comstock MK, Ellis T, Carter JG, Wright C, Stevens WC: **Safety of brachial vs. radial arterial catheters.** *Anesthesiology* 1979, **51** (suppl):S158.
- Bedford RF, Ashford TP: **Aspirin pretreatment prevents post-cannulation radial-artery thrombosis.** *Anesthesiology* 1979, **51**:176-178.
- Davis FM, Stewart JM: **Radial artery cannulation: a prospective study in patients undergoing cardiothoracic surgery.** *Br J Anaesth* 1980, **52**:41-47.
- Jones RM, Hill AB, Nahrwold ML, Bolles RE: **The effect of method of radial artery cannulation on postcannulation blood flow and thrombus formation.** *Anesthesiology* 1981, **55**:76-78.
- Hausmann D, Schulte am Esch J, Fischdick G: **Radial artery cannulation: a prospective study on its complication rate by clinical and sonographic evaluation [in German].** *Anästhesiologie Notfallmed* 1981, **16**:269-273.
- Soderstrom CA, Wasserman DH, Dunham CM, Caplan ES, Cowley RA: **Superiority of the femoral artery for monitoring. A prospective study.** *Am J Surg* 1982, **144**:309-312.
- Russell JA, Joel M, Hudson RJ, Mangano DT, Schlobohm RM: **Prospective evaluation of radial and femoral artery catheterization sites in critically ill adults.** *Crit Care Med* 1983, **11**:936-939.
- Gil RT, Haupt MT, Baharozian MCT, Carlson RW: **Arterial catheter complications: are there differences related to the site of insertion?** *Chest* 1985, **88** (suppl):39S.
- Otero C, Gilsanz FJ, Alvarez J: **Clinical study of 100 cannulations of the radial artery in neuroanesthesia [in Spanish].** *Rev Esp Anesthesiol Reanim* 1985, **32**:229-233.
- Cederholm I, Sorensen J, Carlsson C: **Thrombosis following percutaneous radial artery cannulation.** *Acta Anaesthesiol Scand* 1986, **30**:227-230.
- Weiss BM, Gattiker RI: **Complications during and following radial artery cannulation: a prospective study.** *Intensive Care Med* 1986, **12**:424-428.
- Cronin KD, Davies MJ, Domaingue CM, Worner MJ, Koumoundouros E: **Radial artery cannulation: the influence of method on blood flow after decannulation.** *Anesth Intens Care* 1986, **14**:400-403.
- Naguib M, Hassan M, Farag H, Bodmann RI, Absood GH: **Cannulation of the radial and dorsalis pedis arteries.** *Br J Anaesth* 1987, **59**:482-488.
- Fitzpatrick GJ, McDonald NJ, Moriarty DC: **Radial artery cannulation: a prospective study.** *Ir J Med Sci* 1987, **156**:279-281.
- Leroy O, Billiau V, Beuscart C, Santre C, Chidiac C, Ramage C, Mouton Y: **Nosocomial infections associated with long-term radial artery cannulation.** *Intensive Care Med* 1989, **15**:241-246.
- Bazara MG, Welch M, Golding LAR, Badhwar K: **Comparison of brachial and radial arterial pressure monitoring in patients undergoing coronary artery bypass surgery.** *Anesthesiology* 1990, **73**:38-45.
- Swanson E, Freiberg A, Salter DR: **Radial artery infections and aneurysms after catheterization.** *J Hand Surg* 1990, **15A**:166-171.
- García-Fages LC, Gomar Sancho C, Villalonga A, Pacheco García M, Nalda MA: **Comparative study of radial and cubital arterial catheterization [in Spanish].** *Rev Esp Anesthesiol Reanim* 1991, **38**:268-270.
- Dahl MR, Smead WL, McSweeney TD: **Radial artery cannulation: a comparison of 15.2 and 4.45-cm catheters.** *J Clin Monit* 1992, **8**:193-197.
- Falk PS, Scuderi PE, Sherertz RJ, Motsinger SM: **Infected radial artery pseudoaneurysms occurring after percutaneous cannulation.** *Chest* 1992, **101**:490-495.
- Sfeir R, Khoury S, Khoury Gh, Rustum J, Ghabash M: **Ischaemia of the hand after radial artery monitoring.** *Cardiovasc Surg* 1996, **4**:456-458.
- Wolf S, Mangano DT: **Pseudoaneurysm: a late complication of radial-artery catheterization.** *Anesthesiology* 1980, **52**:80-81.
- Fraile JR, Cuenca J, Gilsanz F, Lueng C, Lora-Tamayo JL: **Post-puncture pseudoaneurysm of the radial artery [in Spanish].** *Rev Esp Anesthesiol Reanim* 1989, **36**:126-127.
- McEllistrem RF, O'Toole DP, Keane P: **Post-cannulation radial artery aneurysm: a rare complication.** *Can J Anaesth* 1990, **37**:907-909.
- Arrowsmith JE: **Extracorporeal pseudoaneurysm: an unusual complication of radial artery cannulation.** *Anesthesia* 1991, **46**:894-895.
- Arnou PM, Costas CO: **Delayed rupture of the radial artery caused by catheter-related sepsis.** *Rev Infect Dis* 1988, **10**:1035-1037.
- Shinfeld A, Ofer A, Engleberg I, Rabi I: **Septic emboli from a radial artery catheter with local manifestations of subacute bacterial endocarditis.** *J Vasc Surg* 1992, **16**:293-296.
- Lindsay SL, Kerridge R, Collett B-J: **Abscess following cannulation of the radial artery.** *Anaesthesia* 1987, **42**:654-657.
- Lagrone MO, Hutton J: **Suppurative thrombarteritis as a complication of arterial cannulation: case report.** *Milit Med* 1984, **149**:219-220.
- Chang C, Dughi J, Shitabata P, Johnson G, Coel M, McNamara JJ: **Air embolism and the radial arterial line.** *Crit Care Med* 1988, **16**:141-143.
- Sánchez-García ML, Riesgo MJ, Benito-Alcalá MC, Gutiérrez Gómez A, Pérez-Pascual C, Rodríguez-Fraile JR, Navia-Roque J: **Late ischemia and carpal tunnel syndrome secondary to catheterization of the radial artery [in Spanish].** *Rev Esp Anesthesiol Reanim* 1997, **44**:201-203.
- Martin SD, Sharrock NE, Mineo R, Sobel M, Weiland AJ: **Acute exacerbation of carpal tunnel syndrome after radial artery cannulation [abstract].** *J Hand Surg Am* 1993, **18**:455-458.
- Quist J, Peterfreund RA, Perlmutter GS: **Transient compartment syndrome of the forearm after attempted radial artery cannulation.** *Anesth Analg* 1996, **83**:183-185.
- Brown MM: **Another complication of arterial cannulation [letter].** *Anaesthesia* 1991, **46**:326.
- Ramsay TM: **Broken needle complicating arterial cannulation [letter].** *Anaesthesia* 1993, **48**:178.
- Tuck M: **Arterial catheter failure.** *Anesth Intensive Care* 1996, **24**:119-120.
- Shah US, Downing R, Davis I: **An iatrogenic arterial foreign body.** *Br J Anaesth* 1996, **77**:430-431.
- Puri VK, Carlson RW, Bander JJ, Weil MH: **Complications of vascular catheterization in the critically ill. A prospective study.** *Crit Care Med* 1980, **8**:495-499.
- Gurman G, Neßler R, Shachar J: **The use of alpha-system set for arterial catheterization.** *Anaesthesist* 1980, **29**:494-497.
- Gurman G, Schachar J: **Femoral artery cannulation in critically ill patients.** *Crit Care Med* 1981, **9**:202-203.
- Thomas F, Burke JP, Parker J, Orme JF, Gardner RM, Clemmer TP, Hill GA, Macfarlane P: **The risk of infection related to radial vs femoral sites for arterial catheterization.** *Crit Care Med* 1983, **11**:807-812.
- Soderstrom CA, Wasserman DH, Ransom KJ, Caplan ES, Cowley A: **Infected false femoral artery aneurysms secondary to monitoring catheters.** *J Cardiovasc Surg* 1983, **24**:63-68.

54. Gordon LH, Brown M, Brown W, Brown EM: **Alternative sites for continuous arterial monitoring.** *South Med J* 1984, **27**:1498-1500.
55. Gurman GM, Kriemermann S: **Cannulation of big arteries in critically ill patients.** *Crit Care Med* 1985, **13**:217-220.
56. Riker AI, Gamelli RL: **Vascular complications and femoral artery catheterization in burn patients.** *J Trauma* 1996, **41**:904-905.
57. Muralidhar K: **Complication of femoral artery pressure monitoring.** *J Cardiothorac Vasc Anesth* 1998, **12**:128-129.
58. Bryan-Brown CW, Lumb PD, Kathirithamby KS, Shapiro B, Azer S: **Axillary arterial catheterization.** *Anesthesiology* 1979, **51** (suppl):S157.
59. Schönstedt R, Oehmig R: **Cannulation of the axillary artery in continuous blood pressure monitoring and blood gas analysis [in German].** *Anästhesiologie Intensivther Notfallmed* 1982, **17**:237-239.
60. Bryan-Brown CW, Kwun KB, Lumb PD, Pia RLG, Azer S: **The axillary artery catheter.** *Heart Lung* 1983, **12**:492-497.
61. Brown M, Gordon LH, Brown W, Brown EM: **Intravascular monitoring via the axillary artery.** *Anesth Intens Care* 1984, **13**:38-40.
62. Mann S, Jones RI, Millar-Craig MW, Wood C, Gould BA, Raftery EB: **The safety of ambulatory intra-arterial pressure monitoring: a clinical audit of 1000 studies.** *Int J Cardiol* 1984, **5**:585-597.
63. Okeson GC, Wulbrecht PH: **The safety of brachial artery puncture for arterial blood sampling.** *Chest* 1998, **114**:748-751.
64. Kaye W: **Invasive monitoring techniques: arterial cannulation, bedside pulmonary artery catheterization, and arterial puncture.** *Heart Lung* 1983, **12**:395-427.
65. Spahr RC, MacDonald HM, Holzman IR: **Catheterization of the posterior tibial artery in the neonate.** *Am J Dis Child* 1979, **133**:945-946.
66. Heinonen K, Kuusela T: **Peripheral artery catheters in very low-birth-weight neonates.** *Acta Paediatr Scand* 1982, **71**:323-324.
67. Abrahamson E, Scott RC, Jurges E, Al-Jawad S, Madden N: **Catheterization of posterior tibial artery leading to limb amputation.** *Acta Paediatr* 1993, **82**:618-619.
68. Prian GW, Wright GB, Rumack CM, O'Meara OP: **Apparent cerebral embolization after temporal artery catheterization.** *J Pediatr* 1978, **93**:115-117.
69. Kapelakis G, Fotopoulos A, Dimakakos P, Androulakis G: **Selective catheterization of peripheral arteries for the monitoring of patients in intensive care units [in German].** *Helv Chir Acta* 1978, **45**:375-379.
70. Gronbeck C, Miller EL: **Nonphysician placement of arterial catheters. Experience with 500 insertions.** *Chest* 1993, **104**:1716-1717.
71. Frezza EE, Mezghebe H: **Indications and complications of arterial catheter use in surgical or medical intensive care units: analysis of 4932 patients.** *Am Surg* 1998, **64**:127-131.
72. Pinilla JC, Ross DF, Martin T, Crump H: **Study of the incidence of intravascular catheter infection and associated septicemia in critically ill patients.** *Crit Care Med* 1983, **11**:21-25.
73. Samaondar W, Freeman JB, Coultsch I, Oxley C: **Colonization of intravascular catheters in the intensive care unit.** *Am J Surg* 1985, **149**:730-732.
74. Ricard P, Martin R, Marcoux A: **Protection of indwelling vascular catheters: incidence of bacterial contamination and catheter-related sepsis.** *Crit Care Med* 1985, **13**:541-543.
75. Damen J, Verhoef J, Bolton DT, Middelton G, Van der Tweel I, Jonge KD, Wver EAT, Nijssen-Karelse M: **Microbiologic risk of invasive hemodynamic monitoring in patients undergoing open-heart operations.** *Crit Care Med* 1985, **13**:548-555.
76. Damen J: **The microbiologic risk of invasive hemodynamic monitoring in adults undergoing cardiac valve replacement.** *J Clin Monit* 1986, **2**:87-94.
77. Norwood SH, Cormier B, McMahon NG, Moss A, Moore V: **Prospective study of catheter-related infection during prolonged arterial catheterization.** *Crit Care Med* 1988, **16**:836-839.
78. Raad I, Umphrey J, Khan A, Truett LJ, Bodey GP: **The duration of placement as a predictor of peripheral and pulmonary arterial catheter infections.** *J Hosp Infect* 1993, **23**:17-26.
79. Bedford RF, Wollman H: **Complications of percutaneous radial-artery cannulation: an objective study in man.** *Anesthesiology* 1973, **38**:228-236.
80. Abadir AR, Ung KA: **Complications of radial artery cannulation.** *Anesthesiol Rev* 1980, **7**:11-16.
81. Bedford RF: **Radial arterial function following percutaneous cannulation with 18- and 20-gauge catheters.** *Anesthesiology* 1977, **47**:37-39.
82. Mimoz O, Pieroni L, Lawrence C, Edouard A, Costa Y, Samii K, Brun-Buisson C: **Prospective, randomized trial of two antiseptic solutions for prevention of central venous or arterial catheter colonization and infection in intensive care unit patients.** *Crit Care Med* 1996, **24**:1818-1823.
83. Band JD, Maki DG: **Infections caused by arterial catheters used for hemodynamic monitoring.** *Am J Med* 1979, **67**:735-741.
84. Lopez-Lopez G, Pascual A, Perea J: **Effect of plastic catheter material on bacterial adherence and viability.** *J Med Microbiol* 1991, **34**:349-353.
85. Sheth NK, Franson TR, Rose HD, Buckmire FLA, Cooper JA, Sohnle PG: **Colonization of bacteria on polyvinyl chloride and teflon intravascular catheters in hospitalized patients.** *J Clin Microbiol* 1983, **18**:1061-1063.
86. Kamal GD, Pfaller MA, Rempke LE, Jebson PJR: **Reduced intravascular catheter infection by antibiotic bonding.** *JAMA* 1991, **265**:2364-2368.
87. Raad II, Darouiche RO, Hachem R, Abi-Said D, Safar H, Darnule T, Mansouri M, Morck D: **Antimicrobial durability and rare ultrastructural colonization of indwelling central catheters coated with minocycline and rifampin.** *Crit Care Med* 1998, **26**: 219-224.
88. Maki DG, Hassemer C: **Endemic rate of fluid contamination and related septicemia in arterial pressure monitoring.** *Am J Med* 1981, **70**:733-738.
89. Donowitz LG, Marsik FJ, Hoyt JW, Wenzel RP: **Serratia marcescens bacteremia from contaminated pressure transducers.** *JAMA* 1979, **242**:1749-1751.
90. Beck-Sague M, Jarvis WR: **Epidemic bloodstream infections associated with pressure transducers: a persistent problem.** *Infect Control Hosp Epidemiol* 1989, **10**:54-59.
91. Wilkins RG: **Radial artery cannulation and ischaemic damage: a review.** *Anaesthesia* 1985, **40**:896-899.
92. Arthus GJ: **Case report: digital ischaemia following radial artery cannulation.** *Anesth Intens Care* 1978, **6**:54-55.
93. Mangano DT, Hickey RF: **Ischemic injury following uncomplicated radial artery catheterization.** *Anesth Analg* 1979, **58**:55-57.
94. Cannon BW, Meshier WT: **Extremity amputation following radial artery cannulation in a patient with hyperlipoproteinemia type V.** *Anesthesiology* 1982, **56**:222-223.
95. Dominguez Pérez F, Calderón NN, Dominguez AA: **Necrosis of the hand produced by cannulation of radial artery [in Spanish].** *Rev Esp Anestesiol Reanim* 1990, **37**:378-379.
96. Mangar D, Laborde RS, Vu DN: **Delayed ischaemia of the hand necessitating amputation after radial artery cannulation.** *Can J Anaesth* 1993, **40**:247-250.
97. Rose SH: **Ischemic complications of radial artery cannulation: an association with a calcinosis, Raynaud's phenomenon, esophageal dysmotility, sclerodactyly, and telegiectasia variant of scleroderma.** *Anesthesiology* 1993, **78**:587-589.
98. Cheng JC, Levinsohn DG, Longaker MT, Gordon L: **Severe ischemia of the hand following concomitant catheterization of the radial artery and systemic administration of dopamine. Case reports.** *Vasc Surg* 1993, **27**:639-643.
99. Sánchez-García ML, Riesgo MJ, Benito-Alcalá MC, Gutiérrez Gómez A, Pérez-Pascual C, Rodríguez-Fraile JR, Navia-Roque J: **Late ischemia and carpal tunnel syndrome secondary to catheterization of the radial artery [in Spanish].** *Rev Esp Anestesiol Reanim* 1997, **44**:201-203.
100. Pauca A, Meredith JW: **Possibility of A-V shunting upon cardiopulmonary bypass discontinuation.** *Anesthesiology* 1987, **67**: 91-94.
101. Czepizak CA, O'Callaghan JM, Venus B, Gravenstein N: **Vascular access.** In *Clinical anesthesia practice*. Edited by Kirby RR, Gravenstein N. Philadelphia: W.B. Saunders Company; 1994: 542-550.
102. Prien Th, Lawin P: **Intravascular catheters [in German].** In *Praxis der Intensivbehandlung*. Edited by Larwin P, Bruessel T, Prien T. Stuttgart, New York: Thieme; 1993:458-476.
103. Rulf ENR, Mitchel MM, Prakash O, Rijsterborg H, Cruz E, Deryck YLJM, Rating W, Schepp RM, Siphanto K, Van Der Woerd A: **Measurement of arterial pressure after cardiopulmonary bypass with long radial artery catheters.** *J Cardiothorac Anesth* 1990, **4**:19-24.