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Review Article

Ultrasound-guided radial artery cannulation in adult and paediatric populations: a systematic review and meta-analysis

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Abstract

Background: Ultrasound is a well-validated adjunct to central venous cannulation; however, previous reviews of ultrasound-guided radial artery cannulation have been inconclusive. The aim of this study was to assess the use of ultrasound in radial artery cannulation in adult and paediatric populations.

Methods: A systematic search of five major databases for all relevant articles published until November 2015 was conducted. Randomized controlled trials of radial artery cannulation with and without ultrasound guidance were included. All studies were assessed for level of evidence and risk of bias. Studies were grouped in adult and paediatric populations for each outcome. A meta-analysis was performed to analyse the data.

Results: Eleven randomized controlled trials (six adult and five paediatric) were found. In both the adult and paediatric populations, there was high-level evidence for significantly improved first-attempt success rate and number of attempts with the use of ultrasound guidance.

Conclusions: This is the first level one systematic review to demonstrate strong evidence for the use of ultrasound guidance in radial artery cannulation in adult and paediatric populations. In the adult population, ultrasound use significantly increased first-attempt success rate, which subsequently resulted in a significant reduction in the number of attempts. The benefits of ultrasound were also shown in the paediatric population, with a significant increase in first-attempt success rate and reduction in the number of attempts. The use of ultrasound as an adjunct to radial arterial cannulation should now be considered best practice.

Key words: ultrasound; radial artery; catheterization; cannulation

Arterial cannulation is a common and important procedure performed to allow repeated arterial blood sampling and continuous blood pressure monitoring.[1–3] The most common site for arterial cannulation is the radial artery, because of the dual arterial supply to the hand, its superficial location, and the relatively low rate of complications.[1] Traditionally, radial artery cannulation has been performed with the aid of pulse palpation and anatomical knowledge.[2]

This invasive procedure is generally safe, but in 1% of patients there are thrombotic, mechanical, or infectious complications.[2–4] The risk of a complication increases with each additional attempt.[4] With each failed cannulation attempt, the procedure becomes increasingly difficult because of vasospasm and haematoma formation causing a weak or even absent pulse.[2] Factors associated with failed radial artery cannulation include obesity, hypotension, oedema, atherosclerosis, and arterial scarring.[1 2] There is also an increased risk of failed cannulation in small children because of the greater proportion of subcutaneous fat and smaller arterial diameter.[4–7]

In an attempt to reduce cannulation failure rates and associated morbidity, the use of ultrasound guidance has grown significantly in popularity.[2 6] The use of ultrasound guidance is a well-validated adjunct for central venous cannulation.[3 6 8] Theoretically, ultrasound guidance provides the ability to overcome the majority of factors associated with cannulation failure. The most recent systematic review and meta-analysis by Gu and colleagues[8] yielded limited results on this topic. A key limitation in previous reviews is the lack of homogeneity between studies, with adult and paediatric data analysed together.[8] There has also been a lack of large high-quality randomized controlled studies to support the use of ultrasound conclusively as a best practice adjunct to radial artery cannulation. Since the most recent systematic reviews and meta-analyses by Shiloh and colleagues[9] and Gu and colleagues,[8] a number of large studies have been released.[1 5 6 10–12] The aim of this systematic review was to compare the traditional palpation technique with ultrasound guidance in the performance of radial artery cannulation of adult and paediatric populations.

Methods

Search strategy

A systematic search of five databases (CINAHL, SCOPUS, PubMed, Medline, and Web of Science) was conducted from the inception of the databases until November 2015. This search was conducted systematically by two independent reviewers searching the following terms: (1) (radial artery) AND (ultrasound) AND (cannulation); and (2) (radial arterial) AND (catheterization) AND (ultrasound). For completeness, a manual reference check of recent reviews and other accepted papers was performed to identify any additional studies.

Inclusion and exclusion criteria

For a study to be included, the study needed to be a randomized controlled trial (RCT) reporting on ultrasound-guided radial artery cannulation (no systematic reviews or meta-analyses). Two reviewers (L. White and A.H.) independently assessed and agreed upon each study for inclusion in this systematic review. Studies investigating the use of radial artery cannulation for the purpose of cardiac catheterization were excluded.

Data extraction

Two reviewers (L. White and A.H.) independently extracted data from each article that met the inclusion criteria. The studies were separated into two groups, those investigating adult and those investigating paediatric populations. The data extracted from each study included the mean age of the study population, indication for arterial cannulation, operator, and clinical outcomes. The data collected by each reviewer were then compared for homogeneity.

Level of evidence, risk of bias, and outcome level of evidence ranking

Each article was evaluated using the Centre for Evidence-Based Medicine (CEBM) levels of evidence introduction document.[13] These studies were then assessed for risk of bias and methodological quality using the Cochrane Collaboration's tool for assessing the risk of bias.[14] The results from each study were then grouped into individual outcomes. These outcomes were each given a level of evidence ranking based on the collective strength of evidence, as follows.[15]

1. High-level evidence: two or more high-quality (quality score ≥4) RCTs with ≥75% consistency in findings.
2. Moderate-level evidence: one high-quality RCT and two or more low-quality studies with ≥75% consistency in findings.
3. Limited evidence: one high-quality RCT or multiple low-quality studies with ≥75% consistency in findings.
4. Conflicting evidence: multiple low- or high-quality studies, or both with ≤75% consistency in findings.
5. No evidence: no studies could be found; may include technique reports.

Statistical analyses

The combined data were analysed using RevMan 5.3 software (The Nordic Cochrane Centre, Copenhagen, Denmark). Differences were expressed as relative risk (RR) with 95% confidence interval (CI) for dichotomous outcomes, and the weighted mean difference (WMD) with 95% CI for continuous outcomes. The Mantel–Haenszel (M-H) random effects model was used. Heterogeneity was assessed using the I^2 statistic, with an I^2>50% indicating significant heterogeneity. A P-value of <0.05 provided evidence of significant RR and WMD. A P-value of <0.10 was used to demonstrate heterogeneity of intervention effects.

Results

Literature search results

The initial systematic literature search yielded 954 citations, of which 34 were retrieved for review. These articles were selected for retrieval based on a review of the abstract, which appeared to meet the search criteria. Of these 34 articles, 11 met the inclusion criteria (Fig. 1). These included six adult (Table 1) and five paediatric RCTs (Table 2).

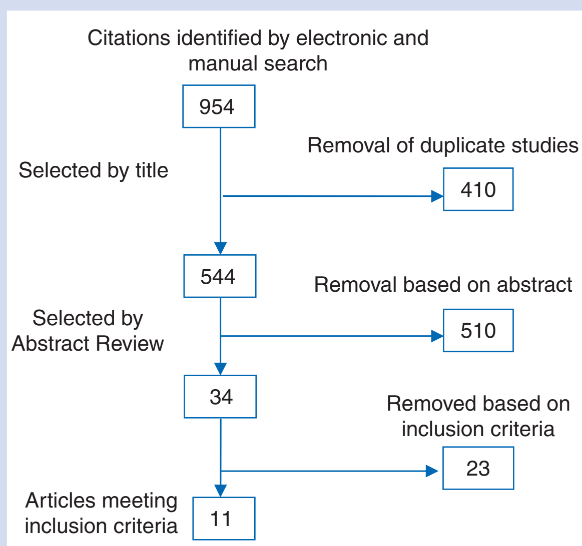

Fig 1 Study identification algorithm. This diagram outlines the filtering process from the literature search through to study inclusion.

Table 1 Adult study characteristics. LAIP, long axis in plane; SAOOP, short axis out of plane. *Level of evidence was assessed using the Centre for Evidence-Based Medicine levels of evidence introduction document.[13] †Same patient with each radial artery cannulated

Study	Number of patients (ultrasound/control)	Location	Ultrasound technique	Operator	Primary outcome(s)	Level of evidence*
Edanaga and colleagues (2012)[16]	36 (24/12)	Operating theatre	SAOOP and LAIP	Anaesthetist (unknown experience)	Number of attempts	2
Hansen and colleagues (2014)[11]	40 (40/40)†	Operating theatre	SAOOP	Anaesthetists with 1 yr of ultrasonography dynamic needle tip positioning experience	1. First-attempt success 2. Number of attempts 3. Time 4. Number of cannulas used	1
Levin and colleagues (2003)[17]	69 (34/35)	Operating theatre	SAOOP	Anaesthetists with no previous ultrasound-guided arterial cannulation experience	1. First-attempt success 2. Number of attempts 3. Time 4. Number of cannulas used	1
Peters and colleagues (2015)[12]	126 (63/63)	Operating theatre	SAOOP	Expert anaesthetists	1. First-attempt success 2. Number of attempts 3. Time 4. Complications	1
Shiver and colleagues (2006)[2]	60 (30/30)	Emergency department	LAIP	Anaesthetists with no previous ultrasound-guided arterial cannulation experience	1. First-attempt success 2. Number of attempts 3. Time 4. Complications	1
Ueda and colleagues (2015)[18]	749 (ultrasound 249; Doppler 244; palpation 256)	Operating theatre	SAOOP	Trainee anaesthetists 1–4 yr with fewer than five previous ultrasound-guided attempts	1. First-attempt success 2. Time 3. Complications	1

Table 2 Paediatric study characteristics. SAOOP, short axis out of plane. *Level of evidence assessed using the Centre for Evidence-Based Medicine levels of evidence introduction document.[13] †Same patient with each radial artery cannulated

Study	Number of patients (ultrasound/control)	Age group	Ultrasound technique	Operator	Indication	Primary outcome(s)	Level of evidence*
Ganesh and colleagues (2009)[19]	152 (72/80)	99 months (mean)	SAOOP	Anaesthetists with fewer than 10 previous ultrasound-guided attempts	Operating theatre	1. First-attempt success 2. Number of attempts 3. Time 4. Number of cannulae used	1
Ishii and colleagues (2013)[7]	59 (59/59)†	18.4 months (mean)	SAOOP	Anaesthetists with no previous ultrasound-guided arterial cannulation experience	Operating theatre	1. First-attempt success 2. Number of attempts 3. Time 4. Complications	1
Schwemmer and colleagues (2006)[4]	30 (15/15)	28 months (median)	SAOOP	Anaesthetists with >20 previous ultrasound-guided arterial cannulations	Operating theatre	1. First-attempt success 2. Number of attempts 3. Time	1
Tan and colleagues (2015)[6]	40 (20/20)	<24 months	Either SAOOP or long axis in plane	Anaesthetic fellows with unknown experience	Operating theatre	1. Number of attempts 2. Time 3. Cost 4. Number of cannulae used	1
Ueda and colleagues (2013)[5]	104 (52/52)	5–6 months (mean)	SAOOP	Anaesthetists with fewer than five previous ultrasound-guided attempts	Operating theatre	1. First-attempt success 2. Time 3. Complications	1

All studies were screened for risk of bias and methodological quality using the Cochrane Collaboration's tool for assessing risk of bias (Table 3). Ten of the 11 studies were level one RCTs (Tables 1 and 2), of which six were high-quality studies (Table 3). The remaining study by Edanaga and colleagues[16] was a low-quality level two RCT (Tables 1 and 3, respectively).

Radial artery cannulation in the adult population

High-level evidence was found for first-attempt success rate in adults. Five studies assessed the impact of ultrasound guidance in radial artery cannulation on first-attempt success rate. Compared with the control group, ultrasound guidance significantly improved first-attempt success rate without significant heterogeneity (RR 1.4; 95% CI 1.28–1.64; P<0.00001; I^2=0%; Fig. 2). The first-attempt success rate improved with ultrasound guidance by 14–37%.[2 11 17 18] This increased the success rate from 34–57% in the control group to as high as 95% in the ultrasound guidance group.[2 11 17 18] This improvement in first-attempt success rate translated into an overall reduction in the number of attempts with ultrasound guidance.

High-level evidence was found, with four of five RCTs (two high and two low quality) showing a reduction in the number of attempts with ultrasound as opposed to the control groups.[2 11 12 17] There was a significant overall reduction in the mean number of attempts (WMD −1.17; 95% CI −2.21 to −0.13; P=0.03; I^2=99%). This resulted in a reduction in the mean number of attempts from 2.2–3.1 in the control group to 1.1–1.6 attempts in the ultrasound guidance group.[2 11 12 17] The low-quality study of expert anaesthetists by Peters and colleagues[12] showed no significant difference in the mean number of attempts, with the mean number of attempts in both groups being approximately one. This contributed to the significant heterogeneity of the data.

Conflicting evidence was found for the time taken to cannulation in adults. Five studies assessed the impact of ultrasound guidance in radial artery cannulation on cannulation time.[2 11 12 17 18] Overall, there was a significant reduction in time to cannulation with ultrasound guidance (WMD −46; 95% CI −86.66 to −5.96; P=0.02). Conflicting evidence was demonstrated through significant heterogeneity (I^2=93%; P<0.00001).

Limited evidence was found for the number of cannulae used in adults. Only two studies assessed the number of cannulae used, one low-quality and one high-quality study.[11 17] Both of these studies showed a reduction in the number of cannulae used with ultrasound *vs* the control group.[11 17] This was demonstrated by a non-significant (P=0.16) WMD of −0.52 (95% CI −1.26 to 0.21) with significant heterogeneity (I^2=100%).

Conflicting evidence was found for complications in adults. Three studies (two high and one low quality) assessed the impact of ultrasound guidance in radial artery cannulation on post-procedure complications.[2 12 18] Two of three studies showed a reduction of complications with ultrasound guidance.[2 12] There was an overall non-significant reduction in complications with ultrasound (RR=−0.49; 95% CI −0.17 to −1.43; P=0.19; I^2=79%).

Radial artery cannulation in the paediatric population

High-level evidence was found for first-attempt success rate in paediatric patients. Four studies assessed the impact of ultrasound guidance in radial artery cannulation on first-attempt success rate.[4 5 7 19] Three (two high- and one low-level) studies demonstrated a significant increase in first-attempt success rate with ultrasound guidance.[4 5 7] The first-attempt success rate increased by 18–47%.[4 5 7] The study by Ganesh and

Table 3 Screening of bias and methodological quality based on the Cochrane Collaboration's tool for assessing the risk of bias

Study	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Selective outcome reporting	Other	Quality score (quality classification)
Edanaga and colleagues (2012)[16]	Unclear risk	Unclear risk	High risk	Low risk	Low risk	Low risk	3 (low)
Ganesh and colleagues (2009)[19]	Low risk	Unclear risk	High risk	Low risk	Low risk	Low risk	4 (high)
Hansen and colleagues (2014)[11]	Low risk	Unclear risk	Low risk	Low risk	Low risk	Low risk	5 (high)
Ishii and colleagues (2013)[7]	Unclear risk	Unclear risk	High risk	Low risk	Low risk	Low risk	3 (low)
Levin and colleagues (2003)[17]	Unclear risk	Unclear risk	High risk	Low risk	Low risk	Low risk	3 (low)
Peters and colleagues (2015)[12]	Unclear risk	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	3 (low)
Schwemmer and colleagues (2006)[4]	Low risk	Unclear risk	High risk	Low risk	Low risk	Low risk	4 (high)
Shiver and colleagues (2006)[2]	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	5 (high)
Tan and colleagues (2015)[6]	Unclear risk	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	3 (low)
Ueda and colleagues (2013)[5]	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	5 (high)
Ueda and colleagues (2015)[18]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	6 (high)

Study	Control Events	Control Total	Ultrasound Events	Ultrasound Total	Weight	Risk ratio M-H, Random, 95% CI
Hansen et al. 2014	23	40	38	40	20.4%	1.65 [1.25, 2.18]
Levin et al. 2003	12	35	21	34	5.5%	1.80 [1.06, 3.06]
Peters et al. 2015	35	62	45	63	21.4%	1.27 [0.97, 1.66]
Shiver et al. 2006	15	30	26	30	10.5%	1.73 [1.18, 2.55]
Ueda et al. 2015	101	256	132	249	42.2%	1.34 [1.11, 1.63]
Total (95% CI)		423		416	100.0%	1.44 [1.28, 1.64]
Total Events	186		262			

Heterogeneity: Tau^2=0.00; Chi^2=3.96, df=4 (P=0.41); I^2=0%

Test for overall effect: Z=5.79 (P<0.00001)

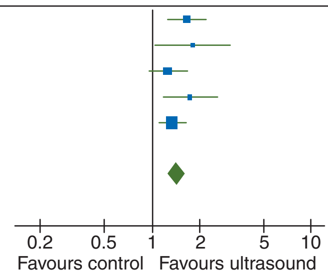

Fig 2 The forest plot depicting first-attempt success in adult patients.

Study	Control Events	Control Total	Ultrasound Events	Ultrasound Total	Weight	Risk ratio M-H, Random, 95% CI
Ganesh et al. 2009	11	80	10	72	18.3%	1.01 [0.46, 2.24]
Ishii et al. 2013	21	59	45	59	50.7%	2.14 [1.48, 3.11]
Schwemmer et al. 2006	3	15	10	15	10.9%	3.33 [1.14, 9.75]
Ueda et al. 2013	8	52	17	52	20.2%	2.13 [1.01, 4.49]
Total (95% CI)		206		198	100.0%	1.96 [1.34, 2.85]
Total Events	43		82			

Heterogeneity: Tau^2=0.04; Chi^2=3.89, df=3 (P=0.27); I^2=23%

Test for overall effect: Z=3.50 (P=0.0005)

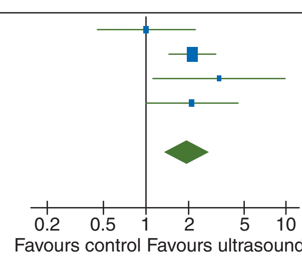

Fig 3 The forest plot depicting first-attempt success in paediatric patients.

colleagues[19] showed no difference between the control and ultrasound guidance groups (P=1.00). There was an overall significant increase in first-attempt success rate without heterogeneity with ultrasound guidance (RR=1.96; 95% CI 1.34–2.85; P=0.0005; I^2=23%; Fig. 3).

As seen in the adult studies, there was also high level of evidence showing a reduction in the number of attempts required for radial artery cannulation. Of the four papers found (two high and two low quality), three demonstrated a significant reduction in the number of attempts with ultrasound guidance.[4 7 19] This resulted in a reduction in the mean number of attempts from 2–6 in the control group to 1–3 attempts in the ultrasound guidance group.[4 7 19] The study by Tan and colleagues[6] measured success within three attempts, showing a negligible (5% reduction; P=0.67) benefit with ultrasound guidance. There was a significant overall reduction in the mean number of attempts with ultrasound (WMD= −1.66; 95% CI −2.95 to −0.38; P=0.01; I^2=98%). The significant heterogeneity was attributable to a higher mean number of attempts in the study by Ganesh and colleagues[19] (control=6; ultrasound guidance=3). With the study by Ganesh and colleagues[19] removed, the significant reduction in mean attempts was maintained with no heterogeneity (I^2=0%).

Conflicting evidence was found for the time taken to cannulation in paediatric patients. Five studies assessed the impact of ultrasound guidance in radial artery cannulation on time to cannulation.[4 5 6 7 19] Two of the five studies showed a reduction in time taken with ultrasound guidance.[5 7] There were also two showing no difference[6 19] and one showing increased[4] time taken with ultrasound guidance compared with the control groups (WMD −11.28; 95% CI −66.18 to 43.62; P=0.69; I^2=79%).

Limited evidence was found for complication rate,[5 7] number of cannulae,[6 7] and cost[6 19] in paediatric patients. The studies reporting each of these outcomes showed no difference between the ultrasound guidance and control groups. There was no difference in the overall analysis for each of these outcomes.

Discussion

The aim of this review was to determine whether there is enough evidence to support the use of ultrasound as a best practice adjunct to radial artery cannulation. As part of this systematic review and meta-analysis, 11 RCTs met our search criteria. This included seven adult and five paediatric studies. This is the first systematic review to show strong evidence for several parameters supporting ultrasound guidance over traditional palpation methods in separate adult and paediatric population groups. This review included only RCTs investigating radial artery cannulation, excluding studies investigating radial artery puncture.[3 10]

This review found high-level evidence for significant benefit with ultrasound guidance for radial artery cannulation with regard to first-attempt success rate (P<0.00001) and the number of attempts (P=0.03) in the adult population.[2 11 17 18] Interestingly, only one study was found during the literature search to show no difference in first-attempt success rate with ultrasound.[1] This study by Miller and colleagues[1] was not included in this review owing to the fact that it was a low-quality[15] cohort study. Furthermore, this was the only study found where the cannulation was not performed by anaesthetists.[1] Likewise, there was one small low-quality level two RCT to show no difference in the number of attempts with and without ultrasound guidance.[16] This was a small study with limited power to detect a significant difference with and without ultrasound guidance.[16]

There were similar benefits associated with ultrasound guidance in the paediatric population. There is now high-level evidence to show that ultrasound guidance significantly (P=0.0005) increases first-attempt success rate.[4 5 7 19] The only study to show no benefit was performed by Ganesh and colleagues.[19] The only identifiable difference in that study when compared with the other three studies was the age of the patients. The patients in the study by Ganesh and colleagues[19] had a mean age of 99 months, as opposed to the three other studies that included much younger patients (5–28 months).[4 5 7] There is also high-level evidence showing a significant (P=0.01) reduction in the number of overall attempts required for radial artery cannulation with ultrasound guidance in paediatric patients.[4 6 7 19]

Importantly, the significant heterogeneity (I^2) demonstrated for the mean number of attempts in both the adult and paediatric populations was not related to any single opposing study result in each analysis. The significant heterogeneity arose from the variation in the mean number of attempts between the control group of each study and the ultrasound group of each study. For example, the control group for the paediatric population ranged from a mean of two to six attempts. Despite the significant heterogeneity, each of these outcomes was ranked as high-level evidence. Both outcomes met the criteria of two or more high-quality (quality score ≥4) RCTs with ≥75% consistency in findings.[15]

In addition to benefits for the patient, ultrasound guidance may also produce institutional cost savings. This was demonstrated only in the adult population, with limited evidence for a non-significant (P=0.16) reduction in the number of cannulae used on each patient.[11 17] The paediatric populations did not demonstrate this. However, the only two paediatric studies to investigate this outcome were Ganesh and colleague[19] and Tan and colleagues.[6] The study by Tan and colleagues[6] demonstrated a negligible benefit with ultrasound guidance in success rate within three attempts and thus no significant difference in the number of cannulae used. Therefore, in the presence of evidence that ultrasound guidance increases first-attempt success and reduces the number of attempts, it is logical to conclude that ultrasound guidance reduces the number of cannulae used and thus institutional cost in paediatric populations and in the adult population. However, additional level one studies would be required to demonstrate this saving.

The proven and potential benefits of ultrasound guidance did not come at the detriment of increased complication rate or time taken to cannulate. Both of these outcomes were unaffected by the use of ultrasound guidance.[2 4–7 11 12 17–19] In fact, there was a small, non-significant benefit for both of these outcomes with ultrasound guidance in the adult population.

Limitations

A key limitation of this study was that several of the outcomes identified, such as number of cannulae used in paediatric patients, did not have enough high-quality RCTs to determine high-level evidence. Another limitation is that the majority of studies were very small, reducing the overall number of patients included in this review. Finally, the significant heterogeneity between studies measuring the mean number of attempts limits the ability to determine objectively the magnitude of benefit with ultrasound guidance.

Conclusion

This is the first level one systematic review to demonstrate high-level evidence that ultrasound is a beneficial adjunct to radial artery cannulation. In the adult population, ultrasound use significantly increased first-attempt success rate, which subsequently resulted in a significant reduction in the number of attempts. The benefits of ultrasound were also shown in the paediatric population, with a significant increase in first-attempt success rate and reduction in the number of attempts. Thus, it is reasonable to conclude that there is sufficient evidence to support the use of ultrasound as a best practice adjunct to radial artery cannulation in adults.

Authors' contributions

Systematic search of the literature: L. White, A.H.
Statistical analysis: L. White
Writing the Introduction section: M.T.
Synthesis of the Results section: L. White, A.H.
Synthesis of the Discussion section: L. White, L. Wallace
Editing: L. Wallace
Referencing and proof reading: M.T.

Declaration of interest

None declared.

References

1. Miller AG, Cappiello JL, Gentile MA, Almond AM, Thalman JJ, MacIntyre NR. Analysis of radial artery catheter placement by respiratory therapists using ultrasound guidance. *Respir Care* 2014; **59**: 1813–6
2. Shiver S, Blaivas M, Lyon M. A prospective comparison of ultrasound-guided and blindly placed radial arterial catheters. *Acad Emerg Med* 2006; **13**: 1275–9
3. Bobbia X, Grandpierre RG, Claret P-G, *et al*. Ultrasound guidance for radial arterial puncture: a randomized controlled trial. *Am J Emerg Med* 2013; **31**: 810–5
4. Schwemmer U, Arzet HA, Trautner H, Rauch S, Roewer N, Greim C-A. Ultrasound-guided arterial cannulation in infants improves success rate. *Eur J Anaesthesiol* 2006; **23**: 476–80
5. Ueda K, Puangsuvan S, Hove MA, Bayman EO. Ultrasound visual image-guided *vs* Doppler auditory-assisted radial artery cannulation in infants and small children by non-expert anaesthesiologists: a randomized prospective study. *Br J Anaesth* 2013; **110**: 281–6
6. Tan TYS, Petersen JAK, Zhao X, Taylor KL. Randomized controlled trial of ultrasound versus palpation method for arterial cannulation in infants less than 24 months of age. *SOJ Anesthesiol Pain Manag* 2015; **2**: 1–3
7. Ishii S, Shime N, Shibasaki M, Sawa T. Ultrasound-guided radial artery catheterization in infants and small children. *Pediatr Crit Care Med* 2013; **14**: 471–3

8. Gu W-J, Tie H-T, Liu J-C, Zeng X-T. Efficacy of ultrasound-guided radial artery catheterization: a systematic review and meta-analysis of randomized controlled trials. *Crit Care* 2014; **18**: R93
9. Shiloh AL, Savel RH, Paulin LM, Elsen L. Ultrasound-guided catheterization of the radial artery: a systematic review and meta-analysis of randomized controlled trials. *Chest* 2011; **139**: 524–9
10. Laursen CM, Pederson RL, Lassen AT. Ultrasonographically guided puncture of the radial artery for blood gas analysis: a prospective, randomized controlled trial. *Ann Emerg Med* 2015; **65**: 618–9
11. Hansen MA, Juhl-Olsen P, Thorn S, Frederiksen CA, Sloth E. Ultrasonography-guided radial artery catheterization is superior compared with the traditional palpation technique: a prospective, randomized, blinded, crossover study. *Acta Anaesthesiol Scand* 2014; **58**: 446–52
12. Peters C, Schwarz SKW, Yarnold CH, Kojic K, Kojic S, Head SJ. Ultrasound guidance *versus* direct palpation for radial artery catheterisation by expert operators: a randomized trial among Canadian cardiac anesthesiologists. *Can J Anaesth* 2015; **62**: 1161–8
13. Howick J, Chalmers I, Glasziou P, *et al*. *The 2011 Oxford CEBM Levels of Evidence (Introductory Document)*. Oxford Centre for Evidence-Based Medicine. Available from http://www.cebm.net/index.aspx?o=5653 (accessed 9 May 2015)
14. Julian PT, Altman DG. *Chapter 8: assessing risk of bias in included studies*. Cochrane Database. Available from http://hiv.cochrane.org/sites/hiv.cochrane.org/files/uploads/Ch08_Bias.pdf (accessed 9 May 2015)
15. Higgins JP, Altman DG, Gøtzsche PC, *et al*. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *Br Med J* 2011; **343**: d5928
16. Edanaga M, Mimura M, Azumaguchi T, Kimura M, Yamakage M. Comparison of ultrasound-guided and blindly placed radial artery catheterisation. *Jpn J Anaesthesiol* 2012; **61**: 221–4
17. Levin PD, Sheinen O, Gozal Y. Use of ultrasound guidance in the insertion of radial artery catheters. *Crit Care Med* 2003; **31**: 481–4
18. Ueda K, Bayman E, Johnson C, Odum N, Lee J. A randomised controlled trial of radial artery cannulation guided by Doppler vs palpation vs ultrasound. *Anaesthesia* 2015; **70**: 1039–44
19. Ganesh A, Kaye R, Cahill AM. Evaluation of ultrasound-guided radial artery cannulation in children. *Pediatr Crit Care Med* 2009; **10**: 45–8

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