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

Leigh White1,2,*, Alice Halpin2, Marianne Turner2 and Laurent Wallace3

1School of Medicine, Faculty of Science, Medicine and Health, University of Wollongong, Wollongong, NSW 2522, Australia, 2Wagga Wagga Base Hospital, Wagga Wagga, NSW, Australia, and 3Campbelltown Hospital, Campbelltown, NSW, Australia

*Corresponding author. E-mail: lw844@uowmail.edu.au

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
There is also an increased risk of failed cannulation in small children because of the greater proportion of subcutaneous fat and smaller arterial diameter.\(^1\)\(^2\)\(^3\)\(^4\)\(^5\)\(^6\)\(^7\) In an attempt to reduce cannulation failure rates and associated morbidity, the use of ultrasound guidance has grown significantly in popularity.\(^2\)\(^3\)\(^5\)\(^6\)\(^8\) 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.\(^6\)\(^8\) 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.\(^1\)\(^5\)\(^6\)\(^10\)\(^11\)\(^12\) 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.†††Same patient with each radial artery cannulated.

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of patients (ultrasound/control)</th>
<th>Location</th>
<th>Ultrasound technique</th>
<th>Operator</th>
<th>Primary outcome(s)</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edanaga and colleagues (2012)</td>
<td>36 (24/12)</td>
<td>Operating theatre</td>
<td>SAOOP and LAIP</td>
<td>Anaesthetist (unknown experience)</td>
<td>Number of attempts</td>
<td>2</td>
</tr>
</tbody>
</table>
| Hansen and colleagues (2014)  | 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)   | 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                 |
2. Number of attempts  
3. Time  
4. Complications | 1                 |
| Shiver and colleagues (2006)  | 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)    | 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

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of patients (ultrasound/control)</th>
<th>Age group</th>
<th>Ultrasound technique</th>
<th>Operator</th>
<th>Indication</th>
<th>Primary outcome(s)</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>
| Ganesh and colleagues (2009)  | 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)   | 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) | 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  
4. Complications | 1                               |
| Tan and colleagues (2015)     | 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)    | 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                               |
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; I²=0%; Fig. 2). The first-attempt success rate improved with ultrasound guidance by 14–37%. This increased the success rate from 34–57% in the control group to as high as 95% in the ultrasound guidance group. 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. 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; I²=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. The low-quality study of expert anaesthetists by Peters and colleagues 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. 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 (I²=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. Both of these studies showed a reduction in the number of cannulae used with ultrasound vs the control group. This was demonstrated by a non-significant (P=0.16) WMD of –0.52 (95% CI –1.26 to 0.21) with significant heterogeneity (I²=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. Two of three studies showed a reduction in complications with ultrasound guidance. There was an overall non-significant difference in complications with ultrasound guidance (RR=0.49; 95% CI –0.17 to 1.43; P=0.19; I²=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. Three (two high- and one low-level) studies demonstrated a significant increase in first-attempt success rate with ultrasound guidance. The first-attempt success rate increased by 18–47%. The study by Ganesh and colleagues showed a significant improvement in success rate with ultrasound guidance (RR=1.64; 95% CI 1.26–2.17; P<0.00001; I²=0%). This resulted in a reduction in the mean number of attempts from 2.21 to 1.26 in the control group to 1.17 to 0.49 in the ultrasound guidance group (WMD –2.21 to –5.96; P=0.003). Conflicting evidence was demonstrated through significant heterogeneity (I²=99%).

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

<table>
<thead>
<tr>
<th>Study</th>
<th>Allocation concealment</th>
<th>Randomisation</th>
<th>Incomplete outcome data</th>
<th>Selective outcome reporting</th>
<th>Quality score (see classification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edanaga and colleagues (2012)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>3 (low)</td>
</tr>
<tr>
<td>Hansen and colleagues (2014)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>5 (high)</td>
</tr>
<tr>
<td>Ishii and colleagues (2013)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>4 (high)</td>
</tr>
<tr>
<td>Levin and colleagues (2003)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>3 (low)</td>
</tr>
<tr>
<td>Peters and colleagues (2015)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>High risk</td>
<td>Low risk</td>
<td>3 (low)</td>
</tr>
<tr>
<td>Schwemmer and colleagues (2006)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>5 (high)</td>
</tr>
<tr>
<td>Shiver and colleagues (2006)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>6 (high)</td>
</tr>
<tr>
<td>Tan and colleagues (2015)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>4 (high)</td>
</tr>
<tr>
<td>Ueda and colleagues (2013)</td>
<td>Low risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>5 (high)</td>
</tr>
<tr>
<td>Ueda and colleagues (2015)</td>
<td>Low risk</td>
<td>Unclear risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>6 (high)</td>
</tr>
</tbody>
</table>
This resulted in a reduction in the mean number of attempts with ultrasound guidance. There was a significant overall reduction in the mean number of attempts with ultrasound compared with the control groups (WMD = 1.96; 95% CI 1.34–2.85; P < 0.0005; I² = 23%; Fig. 2).

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. The study by Tan and colleagues showed no difference, and one showing increased time taken with ultrasound guidance compared with the control group. There was no difference in the overall analysis for each of these outcomes.

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.

Discussion

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 complications. The results of this review are consistent with previous meta-analyses. The use of ultrasound in radial artery cannulation is associated with a decrease in the number of attempts required and an improvement in the first-attempt success rate.

This review showed high-level evidence for the use of ultrasound guidance for radial artery cannulation, with a significant reduction in the number of attempts required (WMD = 1.96; 95% CI 1.34–2.85; P < 0.0005; I² = 23%). Four papers were found, two high and two low quality. Three demonstrated a significant reduction in the number of attempts with ultrasound guidance, whereas one showed no difference. The study by Tan and colleagues showed no difference, and one showed increased time taken with ultrasound guidance compared with the control group. There was no difference in the overall analysis for each of these outcomes.

The study by Tan and colleagues showed no difference, and one showed increased time taken with ultrasound guidance compared with the control group. There was no difference in the overall analysis for each of these outcomes. The study by Tan and colleagues showed no difference, and one showed increased time taken with ultrasound guidance compared with the control group. There was no difference in the overall analysis for each of these outcomes.
attempts (P=0.03) in the adult population.\textsuperscript{7} \textsuperscript{11} \textsuperscript{17} \textsuperscript{18} Interestingly, only one study was found during the literature search to show no difference in first-attempt success rate with ultrasound.\textsuperscript{1} This study by Miller and colleagues\textsuperscript{1} was not included in this review owing to the fact that it was a low-quality\textsuperscript{15} cohort study. Furthermore, this was the only study found where the cannulation was not performed by anaesthetists.\textsuperscript{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.\textsuperscript{16} This was a small study with limited power to detect a significant difference with and without ultrasound guidance.\textsuperscript{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.\textsuperscript{4} \textsuperscript{5} \textsuperscript{7} \textsuperscript{19} The only study to show no benefit was performed by Ganesh and colleagues.\textsuperscript{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\textsuperscript{19} had a mean age of 99 months, as opposed to the three other studies that included much younger patients (5–28 months).\textsuperscript{4} \textsuperscript{5} \textsuperscript{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.\textsuperscript{3} \textsuperscript{6} \textsuperscript{7} \textsuperscript{19}

Importantly, the significant heterogeneity (I\textsuperscript{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 \( \geq 4 \)) RCTs with \( \geq 75\% \) consistency in findings.\textsuperscript{12}

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.\textsuperscript{11} \textsuperscript{17} The paediatric populations did not demonstrate this. However, the only two paediatric studies to investigate this outcome were Ganesh and colleagues\textsuperscript{19} and Tan and colleagues.\textsuperscript{5} The study by Tan and colleagues\textsuperscript{5} 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.\textsuperscript{2} \textsuperscript{4–7} \textsuperscript{11} \textsuperscript{12} \textsuperscript{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 usage 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


Handling editor: J. G. Hardman