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REVIEW ARTICLE

Comparison of ultrasound guidance with palpation and direct visualisation for peripheral vein cannulation in adult patients: a systematic review and meta-analysis

F. H. J. van Loon[1,2,3,*], M. P. Buise[3], J. J. F. Claassen[3], A. T. M. Dierick-van Daele[1,2] and A. R. A. Bouwman[3,4]

[1]Department of Research and Education, Catharina Hospital, Eindhoven, The Netherlands, [2]Department of Technical Nursing Education, Fontys University of Applied Sciences, Eindhoven, The Netherlands, [3]Department of Anaesthesiology, Pain Medicine and Intensive Care, Catharina Hospital, Eindhoven, The Netherlands and [4]Department of Signal Processing Systems and Electrical Engineering, TU/e University of Technology, Eindhoven, The Netherlands

*Corresponding author. E-mail: rick.v.loon@catharinaziekenhuis.nl

Abstract

Background: Peripheral vein cannulation is a routine and straightforward invasive procedure, although i.v. access can be difficult to obtain. To increase the success rate of inserting an i.v. catheter, many devices have been proposed, including ultrasonography. The objective of this study was to compare ultrasound guidance with the traditional approach of palpation and direct visualisation for peripehral vein cannulation. The primary outcome was successful peripheral i.v. cannulation.

Methods: Database search was performed on PubMed, Clinical Key, CINAHL, Cochrane Library of Clinical Trials, and Trip Database (from January 2000 to December 2017). Random-effect meta-analysis was performed to determine the pooled odds ratio for success in peripheral i.v. cannulation.

Results: After database review and eligibility screening, eight studies were included in the final analysis, with a total of 1660 patients. The success rate in the ultrasound group was 81% (n=855), and was 70% (n=805) in the control group, resulting in a pooled odds ratio for success upon ultrasound-guided peripheral i.v. cannulation of 2.49 (95% confidence interval 1.37–4.52, P=0.003). Furthermore, the ultrasound-guided technique reduced the number of punctures and time needed to achieve i.v. access, and increased the level of patient satisfaction, although it did not result in a decreased number of complications.

Conclusions: Ultrasound guidance increases the success rate of peripheral i.v. cannulation, especially in patients with known or predicted difficult i.v. access.

Keywords: catheterisation; peripheral; ultrasonography; vascular access devices

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Editor's key points

- In a meta-analysis that included data from 1660 patients, the authors found an improved success rate for venous cannulation when using ultrasound guidance (over traditional visualisation and palpation).
- Ultrasound guidance reduced number of punctures, improved speed, and improved patient satisfaction. However, the rate of complications was not different.

Peripheral vein cannulation is a routine and straightforward invasive procedure that is performed in approximately 80% of hospitalised patients.[1,2] Peripheral i.v. catheters are required in a broad range of clinical applications, including i.v. drug administration, i.v. hydration therapy, transfusion of blood or blood components, and in situations for which direct access to the bloodstream is necessary.[3–5] Peripheral i.v. catheters are most frequently inserted in veins on the upper extremity, although i.v. access can be obtained on several sites of the body, including peripheral and central veins.[5–7]

The traditional approach of peripheral i.v. cannulation involves visual inspection and palpation of the extremity to locate a vein, followed by a needle puncture and catheter insertion.[8,9] Therefore, peripheral i.v. cannulation requires knowledge of the vascular anatomy to estimate the target vessel location.[10] Notwithstanding, i.v. access can be difficult to obtain, especially in those patients with a lack of visual or palpable apparent veins, smaller veins, and in patients with a known history of a difficult i.v. access.[11]

To increase the success rate of inserting an i.v. catheter, many devices have been proposed as aids to peripheral i.v. cannulation, including ultrasonography.[12] Ullman and colleagues[13] first described an ultrasound-guided technique for central venous cannulation in 1978. The first study of ultrasound-guided cannulation of peripheral veins was a prospective observational study by Keyes and colleagues[14] in 1999, concluding ultrasound-guided i.v. catheterisation to be more successful than the traditional technique. The latest guidelines states that the routine use of ultrasound guidance is recommended for vascular cannulation, especially during central venous and arterial cannulation.[15] In addition, ultrasound guidance can improve the first-attempt success rate and reduce the number of needle passes.[16] Furthermore, ultrasound-guided central venous catheterisation has been shown to be cost-effective when compared with the traditional technique, because it requires less clinician time and causes fewer complications because of an increased first-attempt success rate.[17–19]

After Keyes and colleagues[14] described the use of ultrasound for the identification of suitable veins for cannulation with the Doppler mode, its role in vascular access has greatly expanded. Since then, several primary studies have been designed to compare the use of ultrasound with the traditional technique regarding different outcome measures, while the results upon the first attempt success rate were unambiguous. The objective of this study was to systematically review the results of studies comparing ultrasound with the traditional technique of palpation and direct visualisation, with successful peripheral i.v. cannulation as the outcome of interest. This meta-analysis aimed to prove the utility of ultrasound guidance during peripheral vein cannulation—in terms of efficacy and efficiency—in clinical practice.

Methods

This systematic review and meta-analysis was conducted following the established guidelines from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[20]

Search strategy

For this systematic review and meta-analysis, we searched for publications reporting the role of ultrasound on the success rate of peripheral i.v. cannulation. Both observational and interventional studies were included. Databases of peer-reviewed literature were systematically searched, including PubMed, Clinical Key, CINAHL, Cochrane Library of Clinical Trials, and Trip Database, for manuscripts in the English and Dutch languages as published between January 1, 2000 and December 31, 2017. Google Scholar was searched for additional literature sources. The primary search criteria included "peripheral i.v. access, peripheral i.v. cannulation, and peripheral i.v. catheterisation", which were connected by the Boolean "AND" with the terms "ultrasound, ultrasonography, and ultrasound-guided". The Medical Subject Headings (MeSH) terms "catheterisation, peripheral" and "ultrasonography" were used if appropriate and connected with the Boolean "AND".

Study selection

Studies describing the success rate upon ultrasound-guided peripheral i.v. cannulation, unless the indication for peripheral i.v. cannulation, in adult humans, were included. Studies were excluded for the following reasons: (1) i.v. cannulation on other sites of the body (e.g. lower extremity, central venous) rather than the upper extremity; (2) i.v. insertion of other devices (e.g. central venous catheters, peripheral inserted central venous catheters, dialysis catheters, arterial catheters) rather than short peripheral i.v. catheters; and (3) if the ultrasound-guided technique was compared with any other technique (e.g. light infrared) rather than the traditional technique of palpation and direct visualisation. The flowchart for the study selection procedure is shown in Figure 1. All relevant study results were imported into Mendeley (version 1.17.11; Mendeley Ltd., Elsevier, London, UK), wherein duplicate studies were removed automatically.[21]

Outcome measures

The primary outcome was the success rate of ultrasound-guided peripheral i.v. cannulation, when compared with the success rate upon the traditional technique of palpation and direct visualisation upon peripheral i.v. cannulation. Secondary outcomes included the total number of punctures and the procedure time needed for successful i.v. cannulation, a patient's satisfaction or pain scores, and the incidence of complications. The definition of a difficult i.v. access was not specified, patients were classified regarding the criteria adopted by the original trial investigators.

Data extraction

Initially, two reviewers (F.L. and J.C.) independently screened eligible studies gathered according to the above presented approach on title and abstract, and classified them as being relevant, potentially relevant, or not relevant. In a second phase, the full-text of the articles that were classified as being

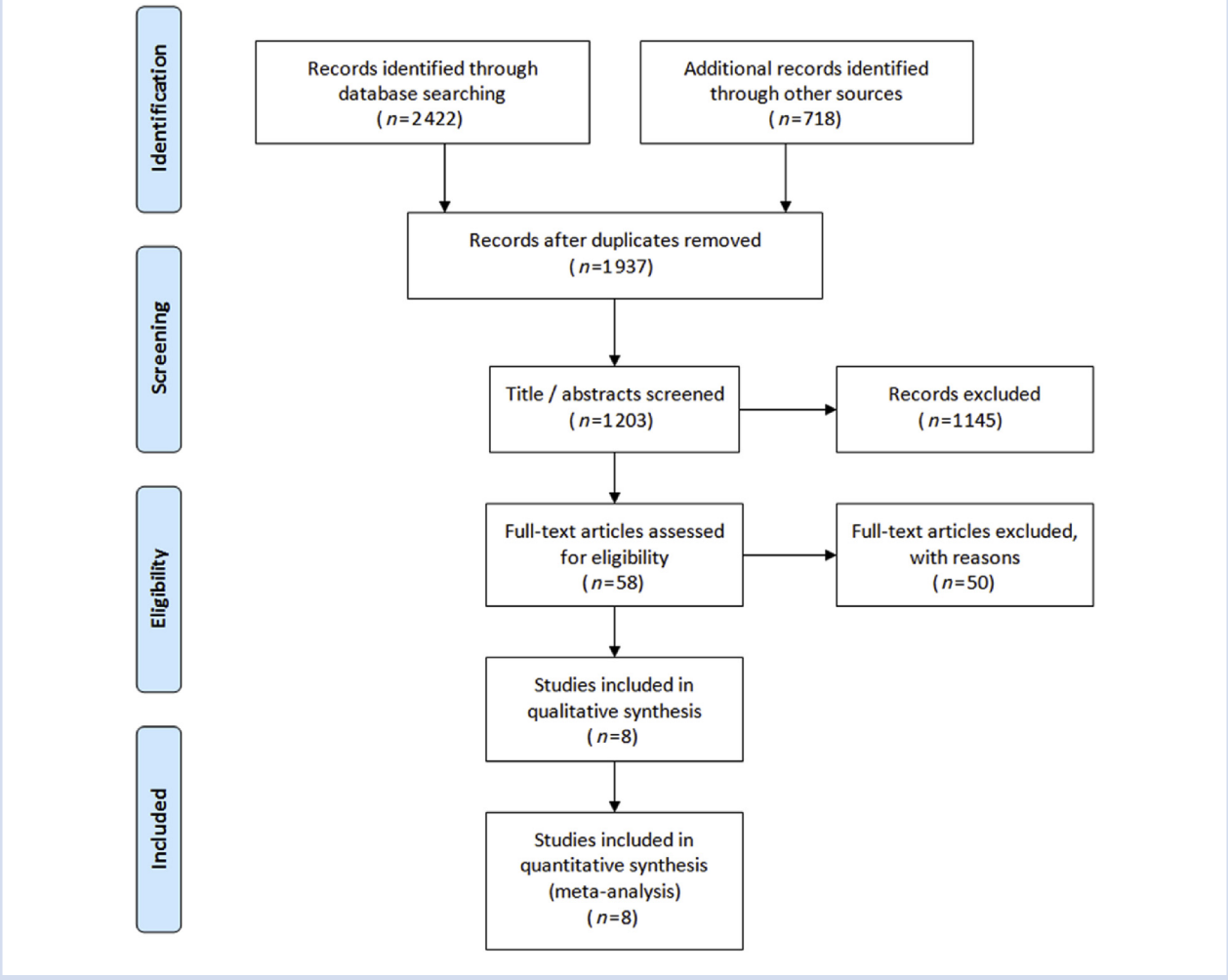

Fig 1. Flowchart of study selection.

relevant were analysed by both reviewers independently. Hereafter, both reviewers decided individually whether or not the depending study was eligible, based on the inclusion and exclusion criteria. Any discrepancy between the reviewers was resolved with a final decision from a third independent investigator (R.A.). Eligibility of studies classified as being potentially relevant in the first phase was also decided by R.A., after which those studies with a positive final decision were included. A data extraction file was created in an Excel data sheet (Microsoft, Redmond, Washington, USA) to register study design details, primary (success rate on the first attempt) and secondary (number of punctures and the procedure time needed for successful cannulation, even as the incidence of complications) outcomes, patient population (number of patients, age, definition of difficult i.v. access), operator type and experience, and the applied ultrasound technique.

Statistical analyses

The weighted mean difference was determined for continues variables, and pooled odds ratios were calculated for categorical variables, including 95% confidence intervals (CI). Random-effect models were used for all outcome measures following the method of DerSimonian and Laird[22] to estimate the pooled odds ratio for success and the risk of complications, and the weighted mean difference for the total number of punctures and the procedure time to successful cannulation. Forest plots were used to present the result for each outcome. The heterogeneity across studies was tested using the I^2 statistic, with I^2>50% indicating significant heterogeneity.[23] Between-study variance was indicated with τ^2 testing, which indicates the variance of the effect size parameters across the population of studies in reflecting the variance of the true effect sizes, with τ^2>1 suggesting the presence of substantial statistical heterogeneity.[23,24] A P value <0.05 was considered as statistically significant throughout this study. SPSS, version 21.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analysis. The meta-analysis was performed using RevMan 5.3 (The Cochrane Collaboration, Oxford, UK).

Results

After database review, removal of duplicates, title and abstract screening, and full-text review, eight studies were selected

and included for final analysis (Fig. 1). As represented in Table 1,[8,25–31] these included five randomised controlled trials and three cohort studies. Reasons for exclusion of studies were cannulation of arteries or central veins, peripheral insertion of long venous catheters and peripherally inserted central venous catheters, and studies in which the ultrasound-guided technique was not compared with a traditional technique. From the included studies, six were carried out on the emergency department, one in a surgical setting (operating room), and one in the ICU. Both single-operator and two-person techniques were used, and short-axis (transverse) and long-axis (longitudinal) viewing techniques. The ultrasound-guided technique was applied by both nurses and physician throughout the studies.

The studies included a total of 1660 patients, of whom 855 were included in the ultrasound-guidance group, and 805 patients in the traditional (control) group. The success rate in the ultrasound group was 81%, whereas a success rate of 70% was recorded in the control group. Hence, ultrasound guidance resulted in a higher success rate in comparison with the traditional technique of palpation and direct visualisation, with a pooled odds ratio for success upon ultrasound-guided peripheral i.v. cannulation of 2.49 (95% CI 1.37–4.52, P=0.003), as shown in Fig. 2.[8,25–31] The heterogeneity χ^2 P-value was 0.002, with an I^2 of 69% and a between study variance τ^2=0.43. Furthermore, of the studies applying the ultrasound-guided technique after multiple failed previous attempts with the traditional technique, the odd ratio for success increased up to 3.23 (95% CI 1.35–7.72, P=0.008, I^2=67%, τ^2=0.63), when compared with an odds ratio of 1.82 (95% CI 0.68–4.90, P=0.23, I^2=69%, τ^2=0.51) in those describing the success rate of ultrasound on the first attempt. As represented in Fig. 3, ultrasound guidance resulted in a reduced number of attempts when compared with the traditional technique with a mean difference of 0.92 (95% CI −0.10 to 1.94, P=0.08, I^2=92%, τ^2=0.97).[25,27–29]

For time to successful cannulation, four studies were included in the analysis.[25,27,28,30] The pooled mean difference was 4.74 min (95% CI −2.09 to 11.57) for ultrasound guidance when compared with the traditional technique (P=0.17, I^2=87%, τ^2=30.13), as shown in Fig. 4. Patients satisfaction, in the meantime, was significant higher in the ultrasound-guided group, with a mean difference of 33% (95% CI 22–43, P<0.001, I^2 0%, τ^2<0.001; Fig. 5).[27,28] Pain scores for both techniques were only denoted in the study of Ismailoglu and colleagues,[29] in which the ultrasound-guided group had a lower score when compared with the control group, with mean (SD) pain scores of 4.77 (1.74) and 6.00 (1.98), respectively (P=0.013). Two studies registered the complications infiltration, arterial puncture, and nerve puncture, however the incidence of complications did not differ significant between both study groups (P=0.82, I^2=56%).[8,27]

Discussion

In this meta-analysis, we observed that the success rate of peripheral i.v. cannulation improves when an ultrasound-guided technique was applied, especially in those patients suffering from multiple failed attempts of peripheral i.v. cannulation with the traditional technique of palpation and direct visualisation. Furthermore, ultrasound guidance resulted in a reduced number of punctures, less time needed to achieve i.v. access, and a higher level of patient satisfaction, however it did not result in a decrease of the number of complications.

Reducing failed attempts of peripheral i.v. cannulation and improving insertion practice may lead to better staff and patient experiences. In addition, successful cannulation results in greater hospital efficiency by using staff time and equipment effectively, which will lead to saved healthcare costs.[32,33] Failure to obtain a peripheral i.v. access on the first attempt oftentimes results in multiple cannulation attempts by different operators and may therefore cause a drain on healthcare provider resources and lead to a delay in diagnoses and treatment.[10,34] Moreover, costs concerning peripheral i.v. cannulation, and therefore healthcare costs in general, increase exponentially with an increased rate of complications.[35] There are several complications related to failure upon obtaining peripheral i.v. access, divided into vascular, infectious, and neurological, including arterial puncture, haematoma formation, local infiltration, extravasation of fluid, superficial or deep vein thrombosis, phlebitis, and paraesthesia because of nerve irritation.[32,33,36,37]

In analogy of previous results, the present analysis confirms the limited benefit of ultrasound for moderate and easy venous access, which remains a remarkable observation. The physical limitations of ultrasound in the nearfield, however,

Table 1 Characteristics of studies included in meta-analysis. CRNA, certified and registered nurse anaesthetist; ED, emergency department; OR, operating room; RCT, randomised controlled trial.

First author and yr	Design	US technique	Sample size	Setting	Practitioner
Aponte 2007[25]	RCT	One operator, short-axis	35	OR	CRNA
Bahl 2016[26]	RCT	One operator	122	ED	Nurse
Bauman 2009[27]	Prospective, non-blinded, two-phase, cohort	One operator, short-axis	75	ED	Physician
Costantino 2005[28]	Prospective, non-blinded, systematically allocated cohort	One operator, short-axis	60	ED	Physician
Ismailoglu 2015[29]	Descriptive, non-blinded, systematically allocated cohort	One and two operators, long-axis	60	ED	Nurse
Kerforne 2012[30]	RCT	Not reported	60	ICU	Nurse
McCarthy 2016[8]	RCT	One operator	1189	ED	Physician
Stein 2009[31]	RCT	One operator, long-axis	59	ED	Physician

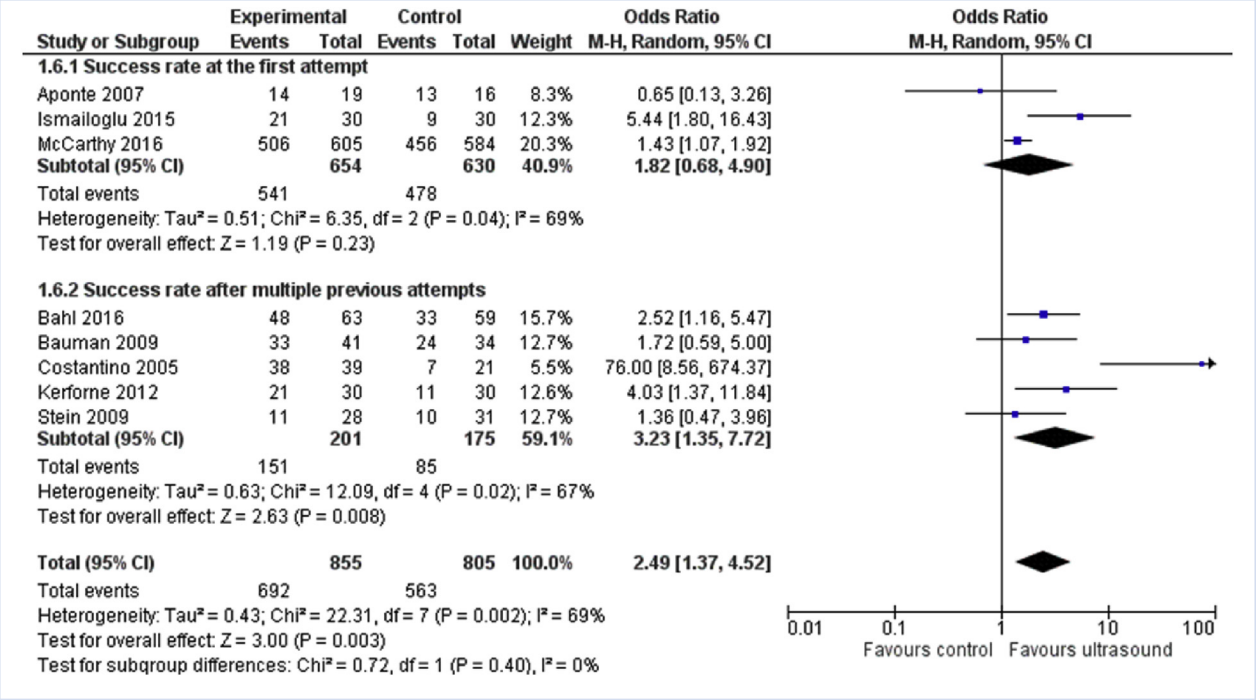

Fig 2. Forest plot comparing the success rate of ultrasound and the traditional technique, with subgroup analysis for studies reporting the first attempt success rate and those reporting the success rate after previous failed attempts.

importantly challenge vascular access in superficial veins. Studies carried out years ago may importantly be affected by the limitations of ultrasound equipment, whereas improvements in technology, including miniaturisation, have led to the development of more compact devices with good image quality.[38,39] Point-of-care ultrasound as performed with a pocketsize device, with appropriate knowledge and training, can be incorporated successfully in patient management, which has been shown to improve management recommendations and outcomes.[40] Based on this, it seems obvious that the first attempt success rate upon peripheral i.v. cannulation is higher in more recently published studies, because of technical innovations and developments of ultrasound machines. Nonetheless, as a result of this meta-analysis, the year of publication appears to have no effect on first attempt success rate of peripheral i.v. cannulation (Table 1).

Therefore, other factors besides ultrasound image quality, such as the used technique (longitudinal or transverse approach) or the skills of the operator also need to be considered in relation to the efficacy of ultrasound-guided peripheral i.v. access. Most studies on the efficacy of ultrasound-guided vascular access do not report on these aforementioned factors. Several studies have compared the different imaging techniques in relation to success rate, although current evidence does not seem to recommend either the longitudinal or transverse approach to obtain the highest success rate.[41–44] In addition to the most optimal approach, the ultrasound skills of the operator are importantly related to the success of ultrasound vascular access. However, as previously mentioned, operator skills are not frequently reported in studies on ultrasound vascular access. Previous evidence clearly show the effect of extensive and appropriate education of physicians before performing an ultrasound-guided technique upon peripheral i.v. cannulation.[45,46] First attempt success rate improved, while central line placement, costs, and complications decreased, after comprehensive training of healthcare providers in inserting an peripheral i.v. access device with ultrasound-guidance.[44–48] The use of

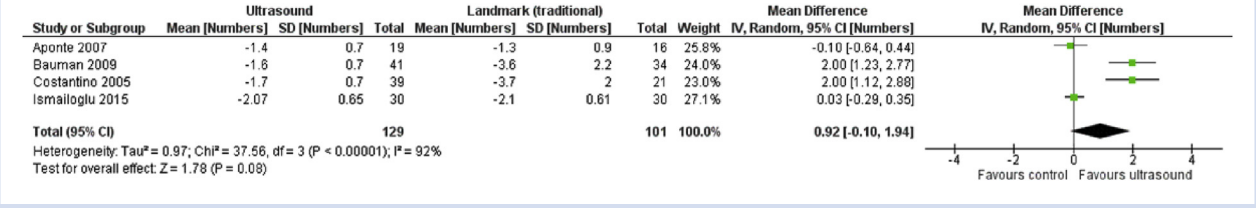

Fig 3. Forest plot comparing the number of attempts needed for successful cannulation with ultrasound and the traditional technique.

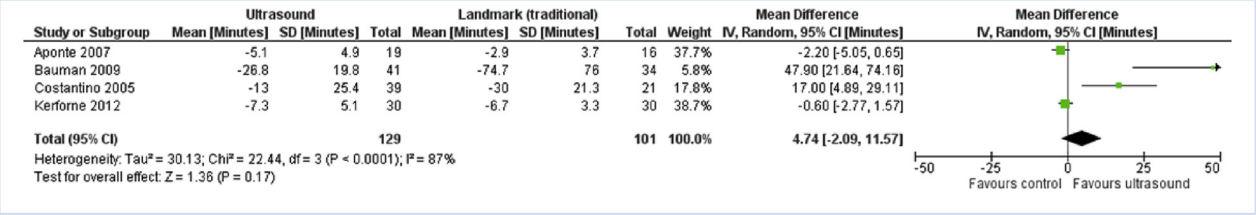

Fig 4. Forest plot comparing the time to successful cannulation with ultrasound and the traditional technique.

ultrasound should be considered early if the vessel cannot be seen directly or palpated and peripheral venous cannulation proves to be difficult, as recommended by the Association of Anaesthetists of Great Britain and Ireland.[49] However, we expect that the application of ultrasound is becoming more accessible in peripheral i.v. cannulation, partly because of the development of point-of-care technology, and due the training of other professionals, including nurses and supporting practitioners.[38,44,46]

Limitations

This review has several limitations. First, not all studies were randomised controlled trials: three cohort studies were also included. A lack of concealment of allocation may have resulted in the existence of selection bias in the included studies.[50,51] Moreover, not applying a blinded adjudication of the treatment may include detection bias, particularly if the analysis was not performed by an independent external researcher.[50,52] Second, the total number of included patients differed between the studies in this meta-analysis. Looking beyond the eight included studies, the study of McCarthy and colleagues[8] enrolled 1189 subjects, which is approximately 76% of the total of patients included for the analysis. Statistical weights used in the meta-analysis take into account the statistical precision of each trial and gave more weight to larger trials.[52] Third, neither identification of patients at high risk nor the definition of a difficult i.v. access was equal between the studies included. Throughout the studies, a difficult i.v. access was reported as the impossibility to identify the target vein by palpation and visualisation on the one hand, or as previous failed attempts or a history of difficult venous access on the other. Differences in this context could have possibly resulted in a changed level of heterogeneity in this meta-analysis. Fourth, of the studies included in this study, peripheral i.v. access was obtained in different departments of the hospital (emergency department, operating theatre complex, ICU), and by different practitioners, including emergency department nurses and physicians, intensive care nurses, and nurse anaesthetists. The various types of practitioner who performed the ultrasound-guided peripheral venous placement differed among the studies, and, as with most ultrasound procedures, there is operator variability in skill sets, which possibly caused heterogeneity among the studies,[52,53] although there is currently no consensus on the number of placements required to determine competency.[53] Patients in the primary studies were recruited from different departments, which could have resulted in heterogeneity because of the variety of patients regarding their physical or clinical condition and the appearance of comorbidities.[52] Sixth, different approaches of ultrasound-guidance were applied in the included studies, involving the longitudinal and the transverse (short-axis) technique. The use of different approaches throughout the included studies, may possibly have affected the presented success rate of the meta-analysis by inducing heterogeneity, as each approach has its advantage, but also its limitations. With the transverse approach, the vessel appears as a circular structure, in which needle identification is done by visualising the hyperechoic needle tip. In this approach, the ultrasound probe must be moved along with the needle to track the tip as an attempt to reach the vessel.[51,55] In the transverse approach, the needle can be walked in by slight advancements of the needle followed by a slight fanning of the probe, paying careful attention to maintain the needle tip in the centre of the vessel at all times.[51,55] With the longitudinal approach, the vessel appears as a long cylindrical structure, providing the advantage of visualising the entire needle while attempting to cannulate the vessel. However, there is insufficient evidence describing whether the longitudinal or transverse approach should be used based on the highest success rate.[47–50] In addition to the discussion on the most optimal approach, it should be underlined that training and knowledge of ultrasound physics are important for success of ultrasound-guided procedures. Ultrasound physics and transducer properties introduce limitations with respect to beam width and elevation plane, that are especially important in case of small targets, such as peripheral vessels.[50–54] Finally, as in most meta-analyses, there may be

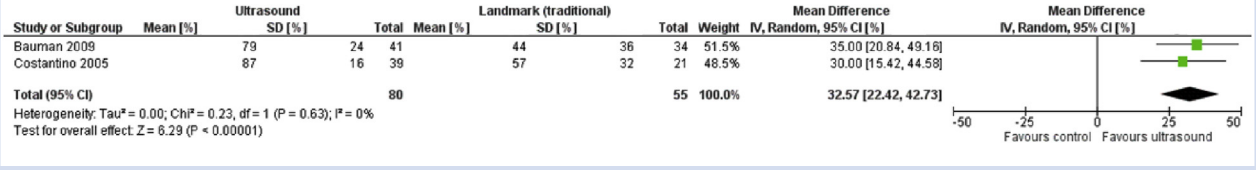

Fig 5. Forest plot comparing patients satisfaction with ultrasound and the traditional technique.

publication bias in this review, although the likelihood of publication bias was minimised by performing an extensive literature search for published and unpublished articles.[50,52]

Random-effect models were used in this meta-analysis to calculate pooled odds ratios regarding the primary outcome, because it does not assume that there is one common treatment effect, but rather a series of different effects.[52] On the contrary, the pooled estimates from random-effect models are more affected by small-study effects, defined as possible biases because of publication bias or other methodological problems commonly associated to small studies.[52] In addition, the variation between studies was taken into account by applying a random-effect model, resulting in larger 95% CIs, while this model is more conservative than fixed-effect models if statistical heterogeneity is present and small-study effects absent.[20,50,52] A recent review by Stolz and colleagues included some identical studies for their analysis, resulting in comparable results as in this review.[8,54] The study of McCarthy and colleagues[8] was not included in the analysis of Stolz and colleagues,[54] because it was published later. We therefore believe that the large sample of patients included by the study of McCarthy and colleagues[8] did not strongly influence the results of this review.

Further research

Further research should focus on the identification of patients at risk with measurement scales at first. Unidimensional scales to classify those patients prospectively should be created and used in daily practice. Clearly, cut-off points should be determined on this measurement scales according to patients' characteristics, by which patients can be classified as being at risk for a failed first attempt or do feature the presence of a difficult i.v. access. Based on these results, additional research should prove to what extent the use ultrasound is efficient and effective upon peripheral i.v. cannulation. The use of ultrasound in those patients at risk may improve the quality of life by increasing the chances of successful venepuncture, and thus reduce the risk of extravasation and material costs, allowing both an economical and a safe situation. Thereby, ultrasound-guidance would only be efficient and effective in patients with a known difficult i.v. access.

Recommendation

Difficult venous access is particularly characterised by non-visible and -palpable veins, where a highly experienced practitioner is required with the use of technological aids to insert the peripheral i.v. access device.[11,44,45] First attempt peripheral i.v. cannulation success would be improved if clinicians with greater procedural experience and an increased perception of the likelihood of success performed the cannulation.[33] The use of ultrasound should be considered early if the vessel cannot be seen directly or palpated, and peripheral venous cannulation proves to be difficult, as recommended by the Association of Anaesthetists of Great Britain and Ireland.[55] However, we expect that the application of ultrasound is becoming more accessible in peripheral i.v. cannulation, partly because of the development of point-of-care technology, and because of the training of other professionals, including nurses and supporting practitioners.[38,50,52]

The technique of ultrasound guidance upon creating peripheral i.v. access was reported to be easy to learn, so ultrasound-guided peripheral i.v. access can safely and effectively be obtained by different healthcare providers.[32,34–36,40–42] Nonetheless, to apply ultrasound guidance to patients upon peripheral i.v. cannulation on low threshold, different healthcare providers need to be trained and gain experience in using this technique.[56] As stated previously, ultrasound physics and transducer properties should be part of the training for understanding of ultrasound related artefacts and pitfalls.[57,58] Furthermore, despite factors related to the procedure of inserting an i.v. catheter, patient-related factors also influence the first attempt success rate.[11,59,60] Prospective identification of the factors and patients at high risk for failure upon peripheral i.v. cannulation, creates a possibility to apply additional techniques in an earlier timeframe.[11,32,61] Furthermore, prospective identification of patients at risk for a difficult i.v. access may result in effective and efficient use of the ultrasound-guided technique in clinical utility.

Conclusion

Ultrasound guidance reduces the risk for a failed attempt upon peripheral vein cannulation and improves the success rate, especially in patients with known or predicted difficult i.v. access. The ultrasound-guided technique reduced the number of punctures and time needed to achieve i.v. access, and increased the level of patient satisfaction, although it did not result in fewer complications.

Authors' contributions

Main investigator: F.L.
Conception and design: F.L., J.C., A.B.
Acquisition of data: F.L., J.C., A.B.
Analysis and interpretation of data: F.L., J.C., A.B.
Drafting the article: F.L.
Revision critically for important intellectual content: M.B., A.D., A.B.
Final approval of the version to be published: M.B., A.D., A.B.

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Declaration of interests

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