Title: Techniques to select site of insertion for a peripheral intravenous catheter with vessel locating devices using light, sounds or tactile actions (or palpations).

Running head: Near Infra Red Venous ANALysis (NIRVANA)

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the [Version of Record](#). Please cite this article as [doi: 10.1111/JOCN.15654](https://doi.org/10.1111/JOCN.15654)

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Niall Higgins designed the work and completed the analysis and interpretation of data;
AND

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(v) acknowledgements;

Sincere thanks to members of the Department of Anaesthesia, Royal Brisbane and Women's Hospital for their invaluable support with collecting data for this study. Thanks also to Professor Samantha Keogh, Queensland University of Technology, for her expert advice on manuscript drafts.

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Article type : Original Article

TITLE: Techniques to select site of insertion for a peripheral intravenous catheter with vessel locating devices using light, sounds or tactile actions (or palpations).

Abstract

Background

Approximately 80% of patients admitted to acute hospitals have at least one peripheral intravenous catheter inserted during their admission, for the administration of fluids and medicines, and/or diagnostic tests, so the failure rate is concerning. New technology may decrease these rates even when used by inexperienced inserters. The choice of insertion site for an intravenous catheter is a known predictor of catheter failure. Therefore, the objective for this study was to evaluate the utility of vessel locating devices for novice clinicians to select catheter insertion sites in the forearm.

Methods

An inter-subject incomplete counterbalanced research design was employed with healthy volunteers. Novice clinicians used either a vessel locating device using light or sound waves or they used palpation to identify relatively superficial veins in the forearm. This was compared to site selection performed by an expert clinician using palpation method only. Measurements of differences were analysed from photos of chosen sites. Bland-Altman agreement analysis was used to plot novice expert agreement. The STROBE checklist was followed in reporting this study (Techniques to select site of insertion for a peripheral intravenous catheter with vessel locating devices (Supplementary File 1)).

Results

A total of 32 novice clinicians used three vessel locating devices and a palpation technique. Novice clinicians did not choose more veins for optimum catheter placement when assisted with vessel locating devices compared to palpation techniques. All methods had a similar mean difference between novice and expert measurements and a similar percentage difference in distance from the expert choice. Bland-Altman agreement analysis did not identify any advantage for the novice with vessel locating devices over palpation.

Conclusion

Vessel locating devices do not enhance the ability of novice clinicians any greater than palpation when selecting suitable forearm veins. If vessel locating device approaches are to be adopted in clinical practice to support better insertion outcomes then current PIVC teaching techniques should include structured vessel locating devices theory and practice.

Keywords

Vessel locating devices, PIVC, Education, Skills development

Summary

Successful insertion of a peripheral intravenous catheter (PIVC) on the first attempt is a challenging procedure for nurses. Careful consideration of the selected site of insertion could modify this risk factor for catheter failure. The aim of this study was to assess if the choice of PIVC insertion site by a novice clinician compared to an expert can be improved with the use of vein locating technology. While there is a range of technological devices available to assist with locating vessels, there needs to be more emphasis from educators on how to select an appropriate insertion site for intravenous therapy.

Relevance to clinical practice

The findings of this study compare and demonstrate preference for PIVC insertion on the forearm between novice clinicians using technology and palpation methods versus an expert using only palpation. The study offers some explanation as to why the use of near infrared devices have not improved success rate for first-attempt peripheral vascular catheter (PIVC) insertion success. This finding suggests that although vessel locating devices can illuminate vessels, not all would routinely be identified by an expert for potential PIVC insertion. There does not appear to be any reason to assume that these devices will be of additional benefit for a novice clinician.

Introduction

The insertion site for successfully inserted peripheral intravenous catheters (PIVC) is a known predictor of phlebitis-associated catheter failure (Gabor et al., 2018; Ray-Barruel et al., 2014). Successful insertion of a PIVC on the first attempt is a challenging procedure for clinicians and success rates can range in adults from 19% to 86% (Aulagnier et al., 2014; Carr et al., 2016). A PIVC that is no longer suitable for care can be the result of infection, phlebitis, dislodgement, infiltration or occlusion (Alexandrou et al., 2018). Careful consideration of the selected site of insertion could modify this risk factor for PIVC failure. Areas of arm flexion for PIVC placement contribute to a higher failure rate for PIVCs because of repeated movement of articulated joint and possible higher microbial count (Blanco-Mavillard et al., 2019; Cundell, 2018). For example, Wallis described independent risk factors for occlusion where the antecubital fossa compared with forearm was HR 1.27 meaning that using the ante-cubital fossa in preference to the forearm increases the incidence of failure due to occlusion by 27% (Wallis et al., 2014). A PIVC sited in the forearm is 60% less likely to fail due to accidental dislodgement than if the back of the hand is selected, it is also easier to secure and is more comfortable (Alexander et al., 2011; Carr et al., 2018; Dillon et al., 2008; Helm et al., 2015; Marsh et al., 2017; Wallis et al., 2014). Given that approximately 80% of patients admitted to acute hospitals have at least one PIVC during their admission, for the administration of fluids and medicines, and/or diagnostic tests the proportion of PIVC failure rate is concerning (Mermel, 2017).

Although the forearm placement of a PIVC is generally preferred by some vascular access specialists over an articulated joint, it is not favoured by inexperienced clinicians because of perceived added difficulty when compared with the hand (Marsh et al., 2018; Rippey et al., 2016; Tan et al., 2016). Repeated needle insertion attempts impact negatively on patient satisfaction causing additional pain and increasing the risk of infection (Cooke et al., 2018; Larsen et al., 2017). Failure to insert a PIVC on the first attempt is often attributed to inexperience and low pre-procedural confidence (Rippey et al., 2016). For example, veins that are fragile or compromised as a result of a patient's clinical presentation require expert clinical judgement and skill to ensure that the patient receives the appropriate care (Lian et al., 2017). An optimum clinical scenario would be when the inserter has full view of the vessel and the margin for error or failed insertion attempt is negligible.

There have been several technological approaches to improve the technique of achieving effective peripheral venous access. More recently infrared light from within the medical spectral window (700-900nm wavelength) has been used to image haemoglobin in red blood cells (Gratton & Fantini, 2004). The ease with which near infrared (NIR) technology can be used, as well as its lower cost compared with standard ultrasound-guided scanning (USS), makes it attractive for training support approaches. However, these approaches have not yet been routinely introduced and evaluated.

First-attempt insertion success rates vary despite a range of decision-making algorithms available to assist clinicians with PIVC insertion (Carr et al., 2017). Inexperienced clinicians or those with low pre-procedural confidence have a lower rate (65%) of PIVC insertion success on the first attempt than a clinician who is highly experienced (90%) (Rippey et al., 2016). Recent studies have examined issues related to PIVC insertion and

identify several practical approaches to avoid common causes of related complications (Alexandrou et al., 2018; Carr et al., 2018; Carr et al., 2016). One issue is site selection. Given that PIVC insertions into shallow veins have a higher success rate, the illumination of relatively superficial veins should be an objective clinical aid for beginning practitioners to identify veins for potential PIVC insertion and be achievable within the scope of their limited practice (Jackson et al., 2013). The literature to date has not demonstrated an improved success rate for first-attempt insertion success by clinicians using NIR devices (Aulagnier et al., 2014). However, no studies have attempted to examine the reasons for this apparent shortcoming (Keogh & Mathew, 2019). Given this evidence gap, the aim of this study was to assess if the choice of PIVC insertion site by a novice clinician compared to an expert can be improved with the use of vein locating technology. We hypothesised that a novice would make an improved PIVC insertion site selection if they could better visualise veins with the help of technology. We compared the inexperienced clinician's choice of potential PIVC insertion sites on the forearm using NIR and USS assistive technologies and palpation with that of an expert using only the traditional palpation method.

Methods

Study design and participants

This was an inter-subject incomplete counterbalanced research design with healthy volunteers. Counterbalancing was performed with repeated measurements by taking some participants to perform one technique and other participants to perform another technique so to avoid any practice or learning effect which may be present. This study design was used because the range of different vessel location methods employed meant that there were a relatively high number of conditions associated with this study. Four vein locating methods were chosen for comparison: (i) Near infrared (NIR) vein viewer that projects a vein image onto the skin; (ii) NIR vein viewer that displays a vein image on the device screen; (iii) Ultrasound guided scanning that uses high frequency sound waves with a probe to display venous anatomy and related structures; and (iv) Palpation method. NIR vessel locating devices (VLD) emit an infrared light generated from an array of light emitting diodes and travel up to 8mm below the skin (Lamperti & Pittiruti, 2013). Photons from the light source are either absorbed by the haemoglobin or are reflected from the surrounding skin. A digital image sensor, such as a charge coupled device, captures a two-dimensional image of the reflected infrared light and processes the information while filtering out the pulsing signal from arteries (Gratton & Fantini, 2004). The resulting enhanced video of the venous system is then either projected by a visible light projector onto the patient or is displayed onto a screen (Hess, 2010; Phipps et al., 2012). It is not known if the level of haemoglobin is an important factor when using a vein finder and what the implications are for anaemic patients but this was beyond the scope of this study.

The study was conducted in a large Australian teaching hospital. The expert was an experienced anaesthetist who had over five years of continual practice in a busy tertiary hospital with substantially more than 1000 PIVC insertions completed during this period of clinical experience. During a weekly tutorial series on basic use of

ultrasound a convenience sample of final year medical students who were defined as novices were invited to take part in the study. These students were provided with a basic training course on USS as part of a four-week tutorial series and included training for each of two other VLDs. They had received basic training on the traditional palpation method as part of their undergraduate studies. Written informed consent was obtained from participants and ethics committee approval was obtained from the Royal Brisbane and Women's Hospital ethics committee (approval number: HREC/15/QRBW/290). The STROBE checklist was followed in reporting this study.

Participants were asked to apply a tourniquet and use one of our 4 methods (VLD and or palpation) to identify the most suitable site for potential PIVC placement. Participants rotated in groups of three through the procedure to use each method - no same device or method was used twice on the same person by any participant. Each method was performed on both sides of each forearm (volar and dorsal) and at least 3cm from the antecubital fossa and 3cm from the wrist. Participants were then asked to place a plastic marker at that chosen site and a photograph taken of the arm directly under a tripod fixed camera (Jakowenko, 2009). This procedure was repeated by an experienced anaesthetist who was asked to choose the single best site for potential PIVC insertion on each arm using palpation only. Comparisons were made between the expert choice and the novice choice on the corresponding side (volar and dorsal) of the forearm. To assist with analysis from photos, a reference ruler was placed next to the arm and a pen mark made on the ulnar styloid as shown in Figure 1 below, another was made on the crease of the wrist. Subsequent distance measurements were made using the ruler tool in Adobe Photoshop (Knoll & Knoll, 2019).

INSERT FIGURE 1 HERE - Figure 1: Pen mark on ulnar head is used as a reference point for subsequent measurements

Statistical analysis

Data were summarised as mean (standard deviation; SD) or frequency (percentage) depending on distribution. Assessment of agreement between each of the four methods (2x NIR devices, USS and Palpation) and the expert choice of PIVC insertion site were performed using a Bland-Altman analysis. This approach was chosen because it would provide a readily observable difference between novice and expert techniques on a scatter plot should it exist. We plotted the difference in measurements from the wrist to the selected PIVC insertion site between each of the techniques used by the novices and the traditional approach used by the expert using MedCalc statistical software version 19.0.6 (Ostend, Belgium). Each vein locating method was investigated by plotting the differences of distances from the wrist to the PIVC insertion site on the vertical axis versus the averages of novice and expert choice on the horizontal axis. Limits of agreement were determined by a 95% prediction interval that is within two standard deviations of the mean difference between measurements.

Results

A total of 32 novice clinicians provided measurements that were compared with an experienced anaesthetist. The mean (standard deviation) age of the 23 that provided demographics was 25 (SD 3.8) years, and 13(57%) were male. Over half 15(65%) had performed 25 or less PIVC insertions and 6(24%) had inserted 26-50 PIVC insertions during their medical training.

There were 37 measurements divided between both left and right arms using the image projecting NIR device, 52 using the screen-based NIR, 28 with the USS and 49 using the palpation technique.

INSERT TABLE 1 HERE - Table 1: Near InfraRed (NIR) image projecting device skin

INSERT TABLE 2 HERE - Table 2: Near InfraRed (NIR) screen-based device

INSERT TABLE 3 HERE - Table 3: Ultrasound-guided scanning (USS)

INSERT TABLE 4 HERE - Table 4: Traditional palpation technique

Fewer measurements were taken using the USS device due to the extra length of time required by novices to locate and select a vein possibly suggesting that more learning is needed to use this compared to the NIR devices. The expert chose the dorsal side of the arm 38(59%) times and 69(42%) were more distal when compared to each of the total 164 site selections made by novices using the various techniques. Table 5 shows the percentage of agreement between choice of PIVC site using each of the four methods and how close this was to the expert choice.

INSERT TABLE 5 HERE - Table 5: Percentage of site choice agreement with expert

The novice choice of vein was the same as the expert half the time ($n=82$; 50%) and was within 3cm of the expert almost half the time ($n=77$; 47%), however only 45(27%) were within 3cm when the same vein was chosen as the expert. Almost three quarters ($n=122$; 74%) of all site selections by novices were within 5cm from the site chosen by the expert, but again this dropped to 71(43%) when considering similar vein choice. Table 6 shows that the mean difference for each method is close to zero but the limits of agreement for the difference between different measures on the forearm range from 9.9 – 15.1 cm.

INSERT TABLE 6 HERE - Table 6: Bias and limits of agreement for each method compared with expert palpation

When agreement between each of the four methods (VLD and Palpation) was assessed, the variability of site selection difference was consistent across all comparisons. This is demonstrated in Figure 2 as the scatter around the bias line does not get larger as the average gets higher.

INSERT FIGURE 2 HERE - Figure 2: Agreement between palpation method used by an expert for PIVC site selection and a novice's choice using each of the four different methods.

The clustering of the USS data to the left of the plot of agreement between the expert's use of palpation method and novice choice using ultrasound guided scanning, reflects that both chose a site that was in the lower part of the arm (i.e. less than 12cm from the wrist).

Discussion

The findings of this study compare and demonstrate what novice preference is when selecting a potential forearm site for PIVC insertion using technology and palpation methods versus an expert using only palpation. The wide limits of agreement for each method demonstrate that there can be a large difference between the site selected for potential PIVC insertion by the expert and that chosen by the novice. This could be explained by the nature of the healthy volunteers in this study having easy-to-find visible veins. However, the expert combines experience and educated judgement to optimize their choice for PIVC placement. In this study we did not find that any of the chosen VLDs provided the novice with any substantial advantage for selecting a potential PIVC insertion site that would be nearer in approximation to that chosen by an expert. The clustering of the USS data in Figure 3 may have been because it was easier for novices to appreciate a vessel's dimensions at the same anatomical position on the forearm. The devices may have been useful in indicating that PIVC site selection was indeed over a vein but the location and suitability of the chosen vein was not improved by use of the device.

Each technique has its own advantages as well as disadvantages. For example, if the clinician applies too much pressure with the ultrasound transducer, superficial veins can be compressed and may make them difficult to locate. Veins that were made visible by the NIR devices were only to the depth that corresponded with the point at which the vein traversed through the fascia of the muscle which in this study was to a depth up to 5mm. This is different to another description of 8mm but could be related to the physique of the study participants (Lamperti & Pittiruti, 2013). Hair on the arm presented a shadowing effect using NIR and veins were unable to be viewed on study participants with substantial hair growth. Tattoos did display a 3-D effect with NIR as well but were not prevalent enough on participants to hamper this study. Although skin colour was not analysed, anecdotally we did not find any related difficulties associated with vein viewing (van der Woude et al., 2013).

All methods appear to have a similar mean difference between measurements and a similar percentage within three centimetres. Although lack of agreement between expert and novice in each of the methods is inevitable, the wide variation between novice and expert may be explained by the large difference in clinical

experience for this procedure. Dexterity may also be a factor related to actual insertion, however, no technique used by a novice appears to increase their ability to choose a site for potential PIVC insertion that is like an expert choice. We did not find that any of the vein viewer devices provided the novice with an advantage over traditional palpation techniques. Although, a novice choosing a vein that is different to an expert on a healthy subject is not clinically significant, this study asserts that visualization is only part of the solution for obtaining first time PIVC insertion success and that site selection is equally as important for clinicians who lack experience with this procedure.

It was thought that approaches such as USS and NIR imaging may help to address PIVC insertion related issues (Parker et al., 2017). There is reported success with USS assisted PIVC placement but it requires specific training to become proficient with this technique (Egan et al., 2013; van Loon et al., 2018). There is also limited evidence on the clinical utility of the various types of NIR based vein viewers (Aulagnier et al., 2014; de Graaff et al., 2013). One study did demonstrate the potential for an experienced operator to identify a greater number of veins with NIR than conventional palpation techniques without the use of a tourniquet but did not indicate how many could be identified by a novice nor how many were suitable for lowering the risk of catheter failure (Chiao et al., 2013). Others have demonstrated that there is equivalence with first time insertion success in a randomised control trial comparing NIR with a traditional approach (Aulagnier et al., 2014). Unfortunately, a recent review of PIVC interventions found that only one NIR study was considered and so could not assess if this technological approach to vein visualisation was effective nor was there sufficient evidence to show that USS techniques increased first time insertion success (Parker et al., 2017).

Relevance to clinical practice

The main strength of this study is its unique comparison of expert use of palpation/ traditional methods versus an equivalent approach by novices that were assisted with VLDs. A limitation is that expert measurements chosen as the gold standard does not imply that these are without error. The high first-attempt insertion success rate by experts, based on the literature reviewed, is best explained by their level of training and appropriate clinical decision-making regarding likelihood of success (Carr et al., 2019). While it could be argued that there is no current agreement on what constitutes a suitable vein for cannulation, the core reason for variation may be because there is no consensus on the best method for procedural skills training for undergraduate clinicians (Alexandrou et al., 2012). It may mean that no particular emphasis is made during training on the rationale for choosing a suitable site for PIVC insertion. Future work could explore the utility of VLDs in conjunction with clinical decision making for appropriate PIVC insertion site selection. It may be possible to teach more effectively using NIR devices to demonstrate the qualities of chosen sites with the enhancement of rapid visualisation.

Conclusion

Accepted Article

These findings suggest that vessel locating devices can illuminate vessels that would not routinely be identified by an expert for potential PIVC insertion. There does not appear to be any reason to assume that these devices will be of additional benefit for a novice clinician. Current training approaches could possibly concentrate more on locating a suitable vessel to cannulate than on actual insertion technique. Senior clinicians could then support novices with a consistent approach that provides a pathway for addressing difficulties as novices become more familiar with this clinical practice.

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Accepted Article

van Loon, F. H. J., Buise, M. P., Claassen, J. J. F., Dierick-van Daele, A. T. M., & Bouwman, A. R. A. (2018). Comparison of ultrasound guidance with palpation and direct visualisation for peripheral vein cannulation in adult patients: a systematic review and meta-analysis. *British Journal of Anaesthesia*, 121(2), 358-366. <https://doi.org/https://doi.org/10.1016/j.bja.2018.04.047>

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TITLE: Techniques to select site of insertion for a peripheral intravenous catheter with vessel locating devices using light, sounds or tactile actions (or palpations).

Table 1: Near InfraRed (NIR) image projecting device skin N=21

	Left n=21		Right n=16		MEAN
	n	%	n	%	
Novice choice more Distal than expert	13	62%	7	44%	53%
Novice chose same vessel as expert	12	57%	8	50%	54%
Same vein choice and within 3cm	5	24%	6	38%	31%
Same vein choice and within 5cm	9	43%	8	50%	46%

5x participants were unable to locate a vein on right arm

Table 2: Near InfraRed (NIR) screen-based device N=28

	Left n=26		Right n=26		MEAN
	n	%	n	n=26	
Novice choice more Distal than expert	16	62%	14	54%	58%
Novice chose same vessel as expert	13	50%	12	46%	48%
Same vein choice and within 3cm	8	31%	5	19%	25%
Same vein choice and within 5cm	13	50%	10	38%	44%

2x participants were unable to locate a vein on left arm

2x participants were unable to locate a vein on right arm

Table 3: Ultrasound-guided scanning (USS) N=14

	Left n=13		Right n=13		MEAN
	n	%	n	%	
Novice choice more Distal than expert	9	69%	9	69%	69%
Novice chose same vessel as expert	5	38%	6	46%	42%
Same vein choice and within 3cm	5	38%	1	8%	23%
Same vein choice and within 5cm	5	38%	4	31%	35%

1x participant was unable to locate a vein on left arm

1x participant was unable to locate a vein on right arm

Table 4: Traditional palpation technique N=25

	Left n=25		Right n=24		MEAN
	n	%	n	%	
Novice choice more Distal than expert	16	64%	11	46%	55%
Novice chose same vessel as expert	14	56%	12	50%	53%

Same vein choice and within 3cm	6	24%	9	38%	31%
Same vein choice and within 5cm	11	44%	11	46%	45%

1x participant was unable to locate a vein on right arm

Table 5: Percentage of site choice agreement with expert

Novice Variable	Within 3cm		Within 5cm	
	Left arm	Right arm	Left arm	Right arm
Near infrared (Accuvein)	6(29%)	9(56%)	17(81%)	12(75%)
Near infrared (IV-eye)	13(50%)	12(46%)	17(65%)	21(81%)
Ultrasound-guided scanning	7(54%)	2(15%)	9(63%)	8(62%)
Palpation	12(48%)	16(67%)	19(76%)	19(79%)

Table 6: Bias and limits of agreement for each method compared with expert palpation

Novice Variable	Novices (n)	Count*	Bias (Mean diff)	Lower LOA (Bias – 1.96 x SD)	Upper LOA (Bias + 1.96 x SD)
Near infrared (Accuvein)	19	37	-0.8	15.1	-11.8
Near infrared (IV-eye)	28	52	0.7	11.2	-9.9
Ultrasound-guided scanning	14	26	1.6	15.1	-11.8
Palpation	25	49	0.5	11.4	-11.8

* Count refers to both L and R arms, not all were able to identify a vein in one or both arms

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