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REVIEW ARTICLE

Ultrasound-guided dynamic needle tip positioning technique for radial artery cannulation

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ABSTRACT

Arterial cannulation remains a cornerstone in the management of critically ill and surgical patients, facilitating continuous blood pressure monitoring, blood gas analysis, and titration of vasoactive drugs. Among the available sites for arterial access, the radial artery is most commonly preferred due to its superficial location, ease of cannulation, and dual blood supply to the hand, which lowers the risk of ischemic complications. Invasive arterial pressure monitoring is regarded as the gold standard, despite potential errors from transducer systems. Cannulation can be guided either by palpation or ultrasound. Although the traditional palpation method remains widely used, ultrasound-guided techniques, particularly Dynamic Needle Tip Positioning, have demonstrated superior first-pass success rates, reduced complications, and faster cannulation times. Dynamic Needle Tip Positioning, a modified short-axis ultrasound approach, enhances needle tip visualization and control during insertion. Across multiple studies, Dynamic Needle Tip Positioning outperformed palpation and some ultrasound methods, though its effectiveness is operator-dependent. Overall, Dynamic Needle Tip Positioning represents a safer, more efficient advancement in arterial line placement.

Keywords: catheterization, palpation, radial artery, ultrasonography, vascular access devices

Introduction

Arterial cannulation remains one of the most significant steps in managing intensive care unit and surgical patients. It is primarily done for repetitive blood testing of for arterial blood gas analysis, adjustment of the vasoactive drugs and recognition of changes in the blood pressure while monitoring the patients to achieve hemodynamic stability. Compared to non-invasive management of blood pressure, invasive measurement through the arterial line is considered better and a gold standard method - despite various errors that can be introduced by the transducers systems[1-3].

Among the various sites used for arterial cannulation, that is the peripheral arteries, radial artery remains one of the commonest used sites for catheterization. The modified Seldinger technique remains the standard technique. However, with further use of imaging, ultrasound guided techniques have become popular. Studies have shown that ultrasound guidance arterial cannulation holds superiority over palpation technique and causes lesser attempts, lesser patient discomfort and complications, with success rates being as high as 51 to 95% (as compared to 34 to 57.5% with palpation)[4,10-13]. However, the studies by Ueda K et al and Levin PD et al showed that ultrasonography guided arterial cannulation success rates may also be low in the range of 53% and 62% as it required training by the performing doctor for which learning curve may be high[11,14].

Inculcating these aspects, continual research has led to the introduction of a relatively novel technique, i.e. dynamic needle tip positioning[7]. Dynamic needle tip positioning technique applies both long axis and short axis views for a better needle positioning and catheterization, with lesser failure attempts. It can be used in both adults and children[3,4].

The present review discusses about the various techniques and sites of arterial cannulation and the use of Ultrasound guided dynamic needle tip positioning techniques in arterial cannulation.

Sites of arterial cannulation

Cannulation in the arterial line can be done in central arteries or peripheral arteries[15]. Common peripheral arterial sites for cannulation include radial artery and femoral artery with others being dorsalis pedis artery. Among them radial artery stands out to be the commonest blood vessel for arterial cannulation[16]. The advantages include presence of dual supply to the hands, easy accessibility, superficial course and lesser incidence of complications (thrombosis, edema, hematoma, nerve injury or rarely infection)[3,4].

Although the assessment of blood pressure in peripheral arteries is similar to aorta, critically ill patients may have underestimated mean arterial pressure in the peripheral arteries. Owing to the status of shock, peripheral arteries such as dorsalis pedis artery maximizes the blood pressure variation of up to 10-20 mm Hg against central aorta - leading to inappropriate vasopressor doses[1,5]. Thus, the use of radial artery becomes much more significant which provides the accurate and most precise blood pressure values in comparison to aorta [17].

Technique

Radial artery catheterization is one of the significant steps for monitoring of arterial blood pressure, which can be measured by a sphygmomanometer or by an arterial catheter[18].

The technique of radial artery catheter insertion is the standard Seldinger technique or the modified Seldinger technique which was first invented in 1953 involving the use of a guide wire, needle, dilator and a catheter [19].

Seldinger technique was introduced in 1953, it uses separate tools–needle, guidewire, dilator, and catheter. The needle enters the artery at 45°, is repositioned, and a guidewire is threaded. Complications include bleeding and vessel perforation[6].

Modified Seldinger technique is similar to the original but with a preassembled needle-catheter unit. The needle is inserted more parallel to the

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artery to avoid the posterior wall. Components are threaded as usual; risks remain the same as the original. Accelerated Seldinger technique uses a fully preassembled catheter with a built-in safety locking needle. It reduces contamination risks and needle-stick injuries while streamlining the process. However, like other methods, it may still cause vessel trauma and catheter failure[6].

Furthermore, after using any of the techniques for insertion, stabilization of the radial artery catheterization is very important, and kinking should be prevented[20]. Various motor movements in the wrist can cause kinking or arterial line dislodgement which may lead to occlusion making the catheter ineffective. Radial artery catheter stabilizers are essential. To improve stabilization, novel techniques have been developed, including a cost-effective method by Abdel-Kader et al, using a diagonally rolled 4×4 inch gauze secured with Hy-tape™, shaped into a horseshoe, and covered with Tegaderm™ (Model 1626W, 10×12 cm)[6]. This setup maintains the catheter's insertion angle, minimizes displacement during wrist flexion, and reduces the risk of kinking or dislodgement.

Arterial cannulation can be done by palpatory technique or by ultrasound guidance[21,22]. The standard approach of arterial cannulation is traditional puncture of the artery by locating its pulse by palpation, followed by inserting an 18 or 20 Gauge (20 G) catheter depending on vessel diameter for peripheral arteries and 16 G for femoral artery[4].

On the other hand, ultrasound can be used for arterial cannulation, through the techniques of long axis in-plane technique and short-axis out-of-the plane technique, with its own advantages and disadvantages[7]. Short-axis out-of-the plane technique involves better delineation of anatomical details of nerves, vessels and veins and various anomalies associated with the anatomy, while long axis in-plane technique holds superiority in visualizing the needle, shaft and the tip[7]. When both these techniques were compared, short-axis out-of-the plane technique, because of its lesser view of the needle tip only as a dot, showed higher the puncture rates of the posterior wall of the vessel[8,9].

Dynamic needle-tip positioning

A modified technique called dynamic needle-tip positioning using the short-axis out-of-plane approach has been reported to enhance arterial catheterization[23]. It is a modified form of ultrasound technique with better results in peripheral venous catheterization success rate in comparison to long axis in-plane or short-axis out-of-the plane technique[7,24]. The dynamic needle-tip positioning approach enables precise imaging of the needle tip by alternatively adjusting the needle and ultrasound probe. It has been described as useful for the catheterization of peripheral vascular structures in both adults and the paediatric population[4].

In the dynamic needle-tip positioning technique, the radial artery **is located** using a short-axis out-of-the plane ultrasound view. An arterial cannula **is advanced** at an angle of about 30° to 45° in the probe's centre until the needle tip **appears** as a bright (hyperechoic) dot on the ultrasound screen. Next, the probe **is shifted** proximally along the forearm until the tip is no longer visible. While holding the probe steady, the cannula **is carefully moved** forward toward the artery until the needle tip **reappears** in the image. This process **is repeated** step by step until the needle tip **is clearly positioned** within the centre of the radial artery's lumen. Finally, the needle **is withdrawn**, the catheter **is inserted** into the artery, the transducer tubing **is connected**, and then recording of arterial pressure waveform **is done**[25].

Comparison of success rates with other techniques

Literature search was done with keywords of "dynamic needle-tip positioning, radial artery cannulation, ultrasound, long axis approach, first-pass success rate" across the databases of Directory of Open Access Journals, Scopus, PubMed, and Elsevier. Only comparative studies done on human population with one of the study groups being dynamic needle-tip positioning were included. A total of 8 studies were found which compared the efficacy of dynamic needle-tip positioning with other techniques for radial arterial cannulation as shown in Table 1.

Table 1: Comparison of DNTP with other techniques in radial artery cannulation

Author (year), Groups (n)	1st pass success	Overall success	Median attempts	Cannulation duration
Kiberenge et al[4] (2017) DNTP (132) vs. TP (128)	83% vs. 48%, p<0.001	89% vs. 65%, P<0.001	1 vs. many	81.5 vs. 76 s, P=0.7
Gopalasingam N et al[26] (2017) DNTP (n=40) vs. TP (n=40)	90% vs. 70%, p=0.022	--	1 vs. 1	77 vs. 88 s, p=0.861
Takeshita et al[23] (2018) DNTP (n=20) vs. conventional US (n=20)	85% vs. 50%, p=0.018	95% vs. 60%, p=0.008	1 vs. 1.5, p=0.01	38 vs. 149, P=0.0003
Bai B et al[28] (2020) DNTP (n=65) vs. AD (n=66)	53.8% 59.1%, p=0.54	86.2% vs. 80.3%, p=0.37	1 puncture: 76.9% vs. 78.78%, P=0.86)	79.7 vs. 47.6 s, p=0.007
Nam K et al[27] (2020) DNTP (n=70) vs. LAIP (n=66)	94.3% vs. 68.2%, p<0.001	100% vs. 100%	1 attempt: 94.28% vs. 68.18%, p<0.001	87.3 vs. 117.7 s, p<0.001
Kim et al[3] (2021) DNTP (n=128) vs. TP (n=128)	85.9% vs. 72.3%, P<0.001	99.2% vs. 93.0%, P=0.01	1 vs. 1	42 vs. 53 s, P<0.001
Safiya SM et al[7] (2023) DNTP (n=57) vs. LAIP (n=57)	96.49% vs. 100%, P=0.094	--	96.5% vs. 100%, P=0.940	48.49 vs. 49.43 s, P=0.527
Mesa et al[25] (2024) DNTP (48) vs. LAIP (48)	97.9% vs. 83.3%, p=0.014	100% vs. 100%, p=1	One vs. many	9.29 vs. 26.16 s, p=0.001
Siddaramaiah MN et al[29] (2024) DNTP (n=60) vs. TP (n=60)	66.7% vs. 66.7%, p=0.794	--	1 vs. 1, P=0.684	60.5 vs. 71.0 s, P=0.066

AD: angle-distance; DNTP: dynamic needle tip positioning; LAIP: long axis in-plane technique; TP: traditional palpation; US: ultrasound

Across the eight studies, dynamic needle-tip positioning significantly showed higher first-pass success rates and fewer complications than palpation or other ultrasound techniques, although there were some exceptions. For instance, Kiberenge et al reported a clear advantage for dynamic needle-tip positioning, with first-pass success of 83% vs. 48% (P<0.001) and overall 5-minute success of 89% vs. 65% (P<0.001); and the median number of attempts was lower for dynamic needle-tip positioning (mostly 1 attempt) compared to palpation (more multiple attempts)[4]. Gopalasingam et al also found dynamic needle-tip positioning superior with first attempt success at 90% vs. 70% (p=0.022), fewer skin perforations (median 1 vs. 1, P=0.016), and similar cannulation times (77 vs. 88 s, P=0.861)[26]. Takeshita et al compared dynamic needle-tip positioning to conventional ultrasound and found higher first-pass success (85% vs. 50%, p=0.018), fewer posterior wall punctures (5% vs. 50%, p=0.0014), fewer attempts (median 1 vs. 1.5, p=0.01), and faster cannulation (38 vs. 149 s, P=0.0003)[23]. Nam K et al also favored dynamic needle-tip positioning with first-pass success of 94.3% vs. 68.2% (p<0.001) and faster cannulation (87.3 vs. 117.7 s, p<0.001)[27].

On the other side, some studies did not find dynamic needle-tip positioning always more successful. Bai B et al saw comparable first-pass success (53.8% vs. 59.1%, p=0.54) and overall success (86.2% vs. 80.3%, p=0.37) when comparing dynamic needle-tip positioning with the angle-distance technique, though dynamic needle-tip positioning had fewer posterior wall punctures (29.2% vs. 56.1%, p=0.002) but longer cannulation times (79.7 vs. 47.6 s, p=0.007)[28]. Kim et al found dynamic needle-tip positioning better than palpation with first attempt success (85.9% vs. 72.3%, P<0.001) and faster times (42 vs. 53 s, P<0.001)[3]. Mesa et al showed dynamic needle-tip positioning outperforming long axis in-plane technique in first-pass success (97.9% vs. 83.3%, p=0.014) and speed (9.29±3.79 vs. 26.16±20.22 s, p=0.001)[25]. Yet, Siddaramaiah MN et al reported no significant difference: first attempt success was identical at 66.7% (p=0.794), median number of attempts was 1 in both groups (p=0.684), and cannulation time slightly favored traditional palpation (60.5 vs. 71.0 s, P=0.066)[29]. Overall, most evidence suggested that dynamic needle-tip positioning is more accurate and efficient, although results can vary by operator skill, technique, and patient population.

Advantages and disadvantages

Dynamic needle-tip positioning enhance the first-attempt success rate, reduce the number of needle passes required, and shorten the median time needed for cannulation. This improvement may result from the clearer visualization of the needle tip provided by the dynamic needle-tip positioning technique[25,30]. However, use of guidewire with modified Seldinger based techniques don't require dynamic needle-tip positioning[26]. Also, Maneuvering dynamic needle-tip positioning is difficult in narrow lumens compared with Short axis technique and requires more expertise.

Conclusion

In conclusion, dynamic needle-tip positioning is a promising advancement for arterial cannulation, providing consistently higher first-attempt success rates and fewer complications compared to traditional palpation and some other ultrasound techniques. The first-pass success rates for dynamic needle-tip positioning are reported to range from 83% up to 97.9%, with significantly fewer posterior wall punctures and lower number of attempts. Cannulation time for dynamic needle-tip positioning is also shorter, although some reports noted slightly longer times depending on operator familiarity. Dynamic needle-tip positioning requires median one attempt across various patient groups, showing reliability and consistency. Dynamic needle-tip positioning was effective in reducing complications and improving procedural control. Thus, dynamic needle-tip positioning is safer, faster, and more successful arterial cannulation, although operator training and experience remain important factors for maximizing its benefits.

Conflicts of interest:

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