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ORIGINAL ARTICLE

Short-Axis Out-of-Plane Approach Versus Oblique-Axis Approach for Ultrasound-Guided Internal Jugular Venous Catheterization in Infants

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Background Central venous catheter (CVC) insertion in infants is a challenging procedure that requires advanced skills. The oblique-axis (OAX) approach for ultrasound (US)-guided CVC insertion combines the advantages of short-axis (SAX) and long-axis approaches, as it allows follow-up of the needle tip and good orientation with the surrounding structures. This study compared US-guided SAX and OAX approaches for internal jugular vein (IJV) catheterization in infants.

Methods This prospective randomized controlled study was conducted in infants who required CVC insertion through the right IJV in the OR. Fifty infants were randomized into SAX and OAX groups based on the approach used.
The primary outcome was the incidence of posterior vein wall puncture (PVWP). The secondary outcomes included other mechanical complications, first-attempt success rate, number of needle redirections, time to flash, and rate of unsuccessful cannulation.

Results The incidence of PVWP was significantly higher in the SAX group (52%) than in the OAX group (12%) (p= 0.005). Flash time was significantly longer in the SAX group (24.52±3.50 s) than in the OAX group (12.84±2.17 s). The first successful attempt rate was non-significantly higher in the OAX group (76%) than in the SAX group (68%). Demographic data, incidence of other complications, number of needle redirections, and rate of unsuccessful cannulations were comparable between the groups.

Conclusion The OAX approach for US-guided CVC in infants was associated with a lower incidence of PVWP and shorter time to flash than the SAX approach.

Keywords Central venous catheter, Infants, Oblique axis, Short axis, Ultrasound.
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INTRODUCTION

Central venous catheters (CVCs) play an essential role in the perioperative anesthetic management of pediatric patients. Indications include complex fluid management, vasopressor administration, and total parental nutrition. The internal jugular vein (IJV) is a popular route for CVC insertion in children because of its anatomical accessibility and reduced infection rates[1].

Owing to their greater technical feasibility and higher success rates, ultrasound (US)-guided CVC insertion techniques are now considered the standard of care. However, in infants, these remain an advanced technique performed only by experienced anesthesiologists[2,3].

There is no consensus on the ideal approach for US-guided IJV catheterization in infants. An ideal approach would be the one associated with higher success and fewer complications, namely posterior vein wall puncture (PVWP), as further advancement of the needle may result in arterial puncture, pneumothorax, hemothorax, catheter misplacement, cardiac perforation and tracheal injury[4].

There are several approaches for US-guided IJV catheterization. The short-axis (SAX) out-of-plane approach is commonly used for CVC insertion in children. In this approach, the needle is aligned with the center of the IJV, which appears circular on the screen. This approach provides a good orientation to the surrounding structures. However, because it is difficult to locate the needle tip precisely, PVWP is common[5].

The long-axis (LAX) in-plane approach enables visualization of the entire needle and follows the path of the needle tip. However, in this approach, the relationship with the adjacent structures, such as the carotid artery, is poorly defined, and accidental arterial puncture may occur. The introducer needle is inserted parallel to the IJV. Any deviation from the US probe makes the needle undetectable. Moreover, the short necks of infants may not accommodate the US probe[6].

The oblique-axis (OAX) in-plane approach combines the benefits of both SAX and LAX approaches. It allows visualization of the IJV, which appears oval on the US screen, together with its neighboring structures, as well as real-time tracking of the needle. In the OAX approach, the probe is placed midway between the SAX and LAX approaches[7].

To date, no previous studies have directly compared the SAX and OAX approaches in infants.

This study aimed to compare the incidence of PVWP and other acute mechanical complications between the US-guided SAX and OAX approaches during IJV catheterization in infants. The first-attempt success rate, time to flash, number of needle redirections, and failure rate were also compared between the groups.

MATERIALS AND METHODS

After obtaining institutional ethical approval and informed consent from parents or guardians, this prospective randomized controlled study was conducted in the Pediatric Surgery Department, Ain-Shams University Hospitals, in infants (aged 1–11 months) requiring central venous access through the IJV as part of their management in the OR. The clinical trial was conducted in accordance with the standards of Helsinki Declaration (1975, revised in 2013).

Exclusion criteria included: INR >1.5, platelet count <50.000/mm3, anticoagulant or antiplatelet therapy, emergency operations, cervical spine injury, infections, wounds, and previous surgical intervention at the cannulation site.

Using computer-generated random numbers, infants were randomly assigned to two equal groups based on the approach used for US-guided catheterization of the IJV: the SAX and OAX groups. CONSORT flow diagram is presented in Figure (1).

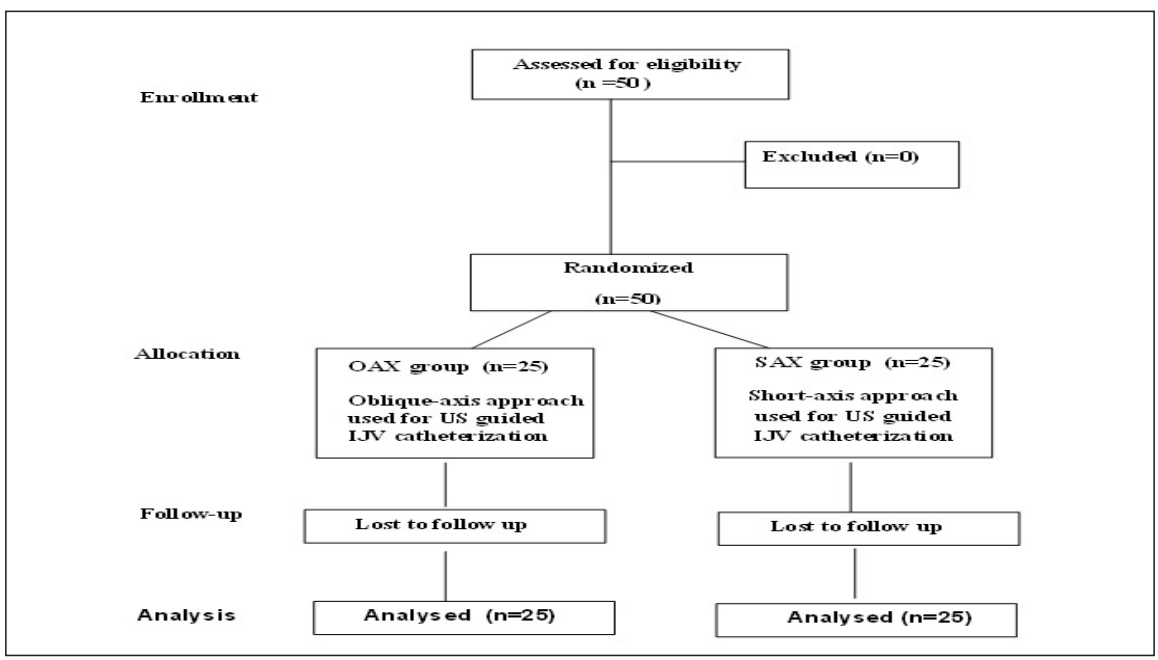

Fig. 1: ONSORT flowchart.

Anesthetic Technique:

The procedure was performed after the induction of general anesthesia and endotracheal intubation in the OR. All infants were monitored using non-invasive blood pressure, ECG, pulse oximetry, temperature probe, and capnography after endotracheal intubation. Anesthesia was induced with either sevoflurane (followed by the insertion of a peripheral IV cannula) or propofol (2mg/kg) in infants arriving at the OR with IV access. This was followed by administration of fentanyl (2µg/kg), atracurium (0.5mg/kg), and endotracheal intubation. All infants were ventilated using pressure-controlled mode after intubation. No Positive End Expiratory Pressure (PEEP) was applied till the completion of the procedure. A fluid warmer and an air-pumped warming device were used for all infants.

Technique for US-guided IJV Cannulation:

In this study, we used a Versana Balance, GE Healthcare, US machine with a high-frequency linear array probe of frequency 6–12MHz; the procedure was performed by the most senior anesthesiologist in the theatre with at least 3 years of experience in pediatric central venous catheterization.

The procedure was performed under completely aseptic conditions, with the infant lying supine and the head in the neutral position, slightly rotated to the contralateral side by no more than 30 degrees, The head was also kept in the Trendelenburg position at approximately 15 degrees.

In the SAX group, the US probe was placed horizontally on the neck perpendicular to the anatomy of the IJV. The IJV in the SAX approach appeared circular and was kept in the center of the US screen. With a pre-mounted syringe, the needle was then introduced at the center of the probe to directly attack the IJV. Indentation of the superior wall was a sign of an impending venous puncture.

In the OAX group, the probe was first placed similar to the SAX approach, and then the lateral end of the probe was rotated upward so that the probe was at a 45° angle with the IJV anatomy. The IJV in the OAX approach appeared oval, and the needle was advanced in alignment with the US probe laterally to medially.

Figures (2, 3) demonstrate the orientation of the US probe on the neck and the corresponding needle puncture sites for both SAX and OAX approaches.

When the needle tip was detected inside the lumen of the vein by US, cannulation was confirmed by aspiration of non-pulsatile blood. The syringe was then removed, and the guidewire threaded through the needle into the vessel (provided no resistance was felt); its position was confirmed by US, followed by advancing a dilator over the wire to create a subcutaneous tract. Using the Seldinger technique, a 4F double lumen catheter was then advanced, followed by removal of the guidewire. Both ports were aspirated to ensure adequate return of blood and were flushed with a sterile saline solution. The position of the catheter within the IJV was confirmed by US. Skin sutures were applied to anchor the catheter and prevent its dislodging. Chest radiography was performed postoperatively for all infants.

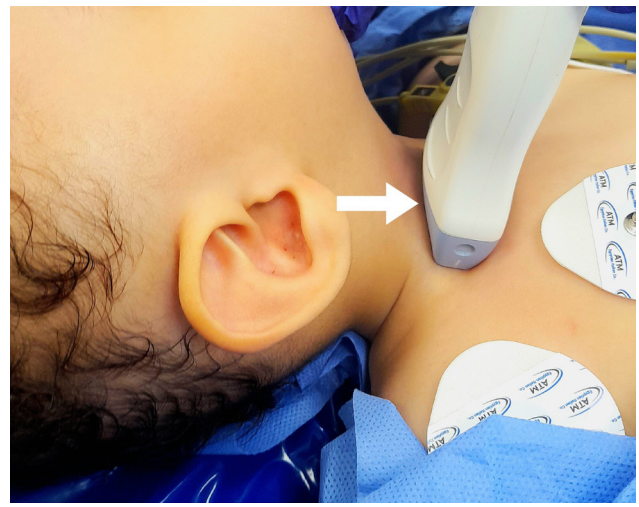

Fig. 2: Ultrasound probe orientation in the short-axis (SAX) approach. The arrow indicates the site of needle insertion.

Fig. 3: Ultrasound probe orientation in the oblique-axis (OAX) approach. The arrow indicates the site of needle insertion.

The primary outcome was the incidence of PVWP (ultrasonographic detection of the needle tip beyond the posterior wall of the IJV). PVWP was identified by the anesthesiologist who performed the procedure.

Secondary outcomes included other acute mechanical complications: subcutaneous hematomas; arterial puncture [return of pulsatile blood through the introducer needle]; pneumothorax, hemothorax, and catheter misplacement [catheter tip detected in a different location from the superior vena cava]; successful first cannulation attempt (venous puncture and guidewire introduction were achieved successfully from the first needle puncture without withdrawal of the needle); number of needle redirections (needle redirected without being completely withdrawn); time to flash (the duration from skin puncture to the appearance of blood within the syringe hub); unsuccessful cannulation (failure of the operator to cannulate the vein within a maximum of three attempts due to failed venous puncture or inability to thread the guidewire, or the need to switch to an alternative approach). Blinding was not possible for this study.

Sample Size Calculation:

Sunny *et al*.,[8] demonstrated a 50% difference in the incidence of PVWP between SAX and OAX groups. Accordingly, considering a significance level of 0.05 and 90% study power, 14 cases per group were required. However, we increased the sample size to 25 per group to compensate for possible dropouts and allow the detection of smaller, yet significant differences.

Statistical analysis:

Continuous variables were expressed as mean±standard deviation for normally distributed data, and as median with interquartile range for non-normally distributed data. For normally distributed continuous variables, comparisons were made using student *t* test. Non-normally distributed continuous variables were compared non-parametrically using the Mann-Whitney *U* test. Categorical data were presented as numbers and percentages and compared using the Fisher's exact test. Statistical analysis was performed using SPSS Inc., version 23.0, Chicago, Illinois, USA.

RESULTS

The groups were comparable in terms of demographic data (Table 1). The incidence of PVWP was significantly higher in the SAX group (52%) than in the OAX group (12%) (P= 0.005). In both groups, the incidence of PVWP was higher in infants aged 1 to 6 months (9 cases in the SAX group and 2 cases in the OAX group) than in infants aged 7 to 12 months (Table 2).

The overall incidence of other mechanical complications was 20% in the SAX group vs 12% in the OAX group. Arterial puncture did not occur in any of the cases in the OAX group (0%) but in 3 cases in the SAX group (12%) (P= 0.237). Only one case of pneumothorax was detected during the study and this was in the SAX group. Subcutaneous hematoma occurred in 1 case in the SAX group (4%), which was associated with multiple attempts together with an arterial puncture. In the OAX group, subcutaneous hematomas were observed in three cases, all of which involved multiple attempts. All subcutaneous hematomas were self-limiting. No cases of hemothorax and catheter malposition, tracheal injury, or cardiac perforation were observed (Table 2).

Table 1: Demographic data:

Age (months)	SAX (n= 25)	OAX (n= 25)	P-value
Age subgroup			
1-6 months	12(48)	15(50)	1
7-12 months	13(52)	15(50)	
Weight (kg)	5.84±2.05	5.7±2.0	0.808
Sex (M/F)	14/11	13/12	1
ASA status			
Class I	10(40)	14(56)	0.396
Class II	15(60)	11(44)	

Data is presented as mean±standard deviation or number of patients (%).SAX= Short-axis; OAX= Oblique-axis; ASA= American Society of Anaesthesiologists.

Table 2: Comparison of PVWP and mechanical complications between the groups:

SAX (n=25)	OAX (n=25)	P-value	
Posterior venous wall puncture			
Overall	13(52)	13(12)	0.005*
1-6 months	9	2	0.069
7-12 months	4	1	0.335
Pneumothorax	1(4)	0(0)	1
Haemothorax	0(0)	0(0)	-
Arterial puncture	3(12)	0(0)	0.237
Subcutaneous hematoma	1(4)	13(12)	
Catheter malposition	0(0)	0(0)	-
Tracheal injury	0(0)	0(0)	-

Data presented as number of patients (%); SAX= Short-axis; OAX= Oblique-axis; *= P<0.05.

Time to flash was significantly longer in the SAX group (24.52±3.50s) than in the OAX group (12.84±2.17s) (P<0.001). The number of first successful attempts was non-significantly higher in the OAX group (76%) than in the SAX group (68%) (P= 0.753) (Table 3). In the SAX group, there were nine cases of unsuccessful first attempt, out of them three ended in unsuccessful cannulation, five cannulations were successful on second attempt, and one cannulation was successful on the third attempt. In the OAX group, there were six cases of unsuccessful first attempt, of which one ended in unsuccessful cannulation, four cannulations were successful on the second attempt, and one cannulation was successful on the third attempt.

The number of needle redirections was comparable between the SAX and OAX groups. Unsuccessful cannulation was more frequent in the SAX group (12%) than in the OAX group (4%), but this difference was not statistically significant (*P*= 0.609) (Table 3). The only case of unsuccessful cannulation in the OAX group was due to a switch to the SAX approach. The three cases of unsuccessful cannulation in the SAX group were due to the inability to cannulate the vein within three attempts, one due to failed venipuncture, and two due to failed guidewire insertion.

Table 3: Comparison of secondary outcomes between the groups:

	SAX (*n*= 25)	OAX (*n*= 25)	*P*-value
First successful cannulation	17(68)	19 (76)	0.753
Unsuccessful cannulation	3 (12)	1 (4)	0.609
Time to flash (sec)	24.52±3.50	12.84±2.17	0.000*
Number of Needle redirections	2 (2,2)	2 (1,2)	0.211

Data is presented as mean±standard deviation; median (Q1,Q3) or number of patients (%). SAX= Short-axis; OAX= Oblique-axis; *= *P*<0.05.

DISCUSSION

The results of the current study revealed that the incidence of PVWP was significantly higher in the SAX group than in the OAX group. There were no significant differences in the incidence of other acute mechanical complications between the groups.

PVWP is a complication that should not be overlooked, as further needle advancement in small infants may lead to injury to the surrounding structures, resulting in complications such as arterial puncture and pneumothorax. In infants, not only is the carotid artery at risk of accidental puncture, but also the vertebral artery, as it is directly related to the IJV compared with that in adults[9]. Inadvertent arterial puncture may result in hematoma, hemothorax, and arterial cannulation, all of which have catastrophic consequences.

The IJV in infants is smaller, thin-walled, and more superficial than that in older children, rendering it more susceptible to PVWP. In a previous study assessing the size of the right IJV in pediatric patients, the IJV diameter in infants was smaller than that in other age groups, with the smallest mean diameter observed in infants aged 0–6 months[10]. This explains the higher incidence of PVWP in infants aged ≤6 months in both groups in the current study.

The OAX approach was introduced by Phelan and Hagerty in 2009[7], combining the advantages of both the SAX and LAX approaches, as it allows real-time follow-up of the needle tip while providing good orientation with the surrounding structures, potentially reducing the incidence of PVWP.

No previous studies have directly compared the OAX and SAX approaches in infants. Sunny *et al*.,[8], compared the US-guided SAX and OAX approaches in 60 adults admitted to the emergency department. There was a significant incidence of PVWP in the SAX group (50%), with no cases of PVWP reported in the OAX group. Similarly, Batllori *et al*.,[11], in their study comparing three approaches: LAX, SAX, and OAX in 220 patients showed that the incidence of PVWP was significantly higher in the SAX approach (11%) compared with the LAX (0%) and OAX (1.4%) approaches. In a study by Wilson *et al*.,[12], the incidence of PVWP was non-significantly higher in the OAX group than in the SAX group. However, it should be noted that Wilson *et al*., conducted their study on gelatin models, but not on human patients.

Regarding "performance metrics," the time to flash in the current study was significantly short in the OAX group, indicating accurate needle guidance. The first-attempt success rate, number of needle redirections, and number of unsuccessful attempts were comparable between the groups.

The first-attempt success rate is particularly important in infants, as multiple attempts may lead to hematoma formation with subsequent narrowing of the already small vein caliber. All cases of subcutaneous hematoma in both groups in the current study were related to multiple cannulation attempts.

In adults, although Batllori *et al*.,[11], reported that both the SAX and OAX approaches had a higher first needle pass success rate than the LAX approach, two meta-analyses[13,14], showed that all three approaches were comparable. The lack of superiority of the SAX and OAX approaches regarding the first-attempt success rate has also been highlighted in previous randomized trials[8,15], and a pooled meta-analysis[16]. A syringe-free OAX approach was described by Ince *et al*.,[17], in which the guidewire was mounted onto the syringe before skin puncture to allow US guidance of the entire procedure, including guidewire insertion, without interruption. This technique was associated with a significantly lower number of attempts and needle redirections than the SAX approach.

In this context it should be noted that although these "performance metrics" are important to assess feasibility, efficiency and safety of the procedure, they remain highly influenced by personal and technical factors.

Interestingly, several techniques have been proposed to improve needle visualization in the pediatric population using the SAX approach. Among these techniques is the combination of the SAX and LAX approaches, where the SAX approach is used to puncture the skin and progress the needle to the anterior vein wall, followed by repositioning of the US probe, and using the LAX approach to puncture the vein. This approach is non-inferior to LAX in preventing PVWP in infants and small children[18].

Another technique is the "vanishing target sign," in which the US probe is fanned distally as the needle advances. The US plane extends beyond the needle tip, causing it to disappear or vanish and then reappear, allowing better follow-up of the needle tip. This technique, also referred to as dynamic needle tip positioning, is associated with a higher first-attempt success rate and fewer complications, namely carotid artery puncture, than the LAX approach in neonates[19].

There are several technical factors we would like to address to ensure reproducibility of the results:

1. In the current study, the technique was performed by the most expert anesthesiologist in the theatre, who had at least 3 years of experience in inserting US-guided CVCs in infants.

2. The US machine and probe were unified for all infants. Accordingly, the use of a US machine with different image qualities and performing the technique by a less expertise operator may yield variable results and affect their reproducibility.

3. The US probe used in this study was the standard pediatric linear probe, as it was the one available in theatre. However, it should be noted that the hockey stick probe is an attractive choice because it has a smaller footprint and may be better accommodated by the short necks of infants.

4. In the current study, the head was maintained in a neutral position during the procedure while applying slight rotation to the contralateral side, not exceeding 30 degrees, Previous studies have demonstrated that excessive head rotation increased the overlap between the IJV and carotid artery, increasing the risk of arterial puncture[20].

LIMITATIONS

Unfortunately, ultrasonographic detection of PVWP is highly subjective, with the possibility of artifacts and echoes from surrounding structures being misinterpreted as PVWP, resulting in an overestimation of the incidence of PVWP, particularly in the SAX group. Additionally, blinding was not possible in this study.

Future aspects:

As previous studies comparing the SAX and OAX approaches were conducted in the adult population, the results of these studies cannot be reliably applied to infants. Similar multi-center studies with large sample sizes in the same context should be conducted in infants to support the results of the current study and allow for generalization of the results. Confounding factors that may lead to technical difficulties should also be considered. One of these difficulties is the operator handedness. Theoretically, cannulation of the right IJV is easier for right-handed operators. Another confounding factor is the size of the IJV, which should ideally be1.5 to 2 times the size of the carotid artery[21,22], during ultrasonographic screening to allow straightforward cannulation.

In the cannula over-wire technique, the IJV is transfixed using a short peripheral cannula, which is then withdrawn after removal of the needle, and a straight tip guidewire is threaded after blood flow appears[23,24]. This technique has gained popularity in neonates and small infants because of its high success rates. Comparing the success rate and safety of this approach, in which PVWP is performed intentionally, to the OAX approach, which potentially guards against PVWP, should be a target for future research in neonates and infants.

CONCLUSIONS

The OAX approach for US-guided CVC in infants was associated with a lower incidence of PVWP and shorter time to flash than the SAX approach.

CONFLICT OF INTERESTS

There are no conflicts of interest.

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