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ORIGINAL SCIENTIFIC REPORT

Evaluation of a Novel Bony Landmark-Based Method for Teaching Percutaneous Insertion of Subclavian Venous Catheters in Pediatric Patients

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Abstract

Background Surgical trainees performing subclavian vein (SCV) cannulation often incorrectly perceive needle trajectory and anatomical relations. As surface landmark-based methods derived from adult surgical practice may be less effective in younger patients, we developed and evaluated a novel bony landmark-based method for teaching SCV cannulation for central venous access device (CVAD) placement in children.

Methods Over 2 sequential 3-year periods, pediatric surgical trainees were taught infraclavicular SCV cannulation via surface- and bony-landmark approaches, respectively. We prospectively recorded patient, surgeon and operative details on all Hickman line and port-a-cath insertions placed by trainees as the first surgeon via percutaneous infraclavicular SCV puncture and compared procedural outcomes and complications across both periods.

Results Of 271 cases included in the study, trainees performed 52 (50.5%) and 92 (54.8%) procedures in the first and second periods, respectively. Patients in both periods did not differ by gender, disease, CVAD device, or prior CVAD, chemotherapy or infection status. In the second (bony landmark) period, although patients were younger (6.0 vs. 8.7 years, $P = 0.003$) mean procedural duration was shorter (42.5 vs. 58.3 min, $P < 0.001$). Also, cannulation attempts and complication rates did not differ significantly between study periods ($P = 0.257$ and 1.0, respectively).

Conclusions With the bony landmark approach, trainees could perform the procedures faster despite operating on younger patients, without impacting complication rates and cannulation attempts. Bony landmarks may better approximate SCV position across a range of ages, thus improving the consistency of SCV cannulation in CVAD placements in children.

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Introduction

Central venous catheterization is performed as commonly on pediatric patients as on adults. While it is among the most common procedures carried out by pediatric surgeons [1], placement techniques are largely derived from adult surgical principles, despite the greater variations in body size and habitus among children. Central venous catheters can be inserted into the internal jugular, femoral or subclavian veins (SCV), but placement into the SCV has several advantages: it is associated with lower risk of infection and symptomatic thrombosis, it continues to remain patent even in shock, and the fixation of the catheter is more comfortable over the upper torso than at other sites such as the neck and groin [2–4].

The SCV is not amenable to full in-plane visualization with ultrasound, reducing its benefit as an adjunct for intraoperative guidance. Furthermore, in pediatric patients, more advanced technical skills and specialized ultrasound probes are required [5, 6]. Thus, cannulation is often performed via blind percutaneous infraclavicular approach—a method widely adopted since its introduction in 1952 [1, 3, 7, 8]—using the clavicle as a landmark to locate it. However, due to its proximity to important structures in the neck and thorax, SCV cannulation can result in complications such as arterial puncture, hemopneumothorax, hematoma, and thrombosis [1, 2, 4].

Three-dimensional visualization of structures is essential in learning and performing SCV cannulation, with the commonest technical errors related to incorrect visualization of anatomical structures and wrong needle trajectory. To improve accuracy of mental visualization of the venous anatomy and surrounding structures, we designed and taught pediatric surgical trainees a new approach using bony landmarks instead of surface landmarks. In comparison with the surface landmark approach, the bony landmark approach allows surgeons to visualize the location and depth at which the SVC lies in 3 dimensions and direct the entry point and depth of the cannulating needle accordingly. This study aimed to evaluate this novel approach for teaching SCV cannulation in pediatric patients.

Materials and methods

Patients

We prospectively recorded patient, surgeon and operative details for all pediatric patients who had undergone percutaneous SCV catheterization for placement of long-term indwelling central venous access devices in KK Women's and Children's Hospital, Singapore, from July 2011 to June 2017 using a data template. The study period consisted of two equal time periods where two different approaches to SCV puncture were taught—study period 1 from July 2011 to June 2014 where a surface landmark method was used, and study period 2 from July 2014 to June 2017 where the bony landmark method was used. In study period 2, only cases performed using the bony landmark method were included. With Institutional Review Board approval, information was accessed from patients' online medical charts and operation records. We included all insertions of Port-a-caths and Hickman lines that utilized percutaneous SCV cannulation by general pediatric surgeons during the study periods and performed subgroup analysis for procedures where supervised pediatric surgical trainees were operating as the first surgeon.

Surgical approach

All procedures were performed in the operating room under sterile aseptic conditions with the patient under general anesthesia with an intravenous infusion. A roll was placed under the shoulders and the neck extended. Skin preparation was performed with chlorhexidine gluconate 2% w/v with isopropyl alcohol 70% w/v, and povidone iodine 10% w/v with isopropyl alcohol 70% w/v. The patient was fully covered with sterile drapes, exposing only the upper chest and neck, and placed in the Trendelenburg position. Intraoperative ultrasound evaluation of the upper chest veins was not utilized for subclavian access, and only performed preoperatively to assess venous patency in patients who have had prior central venous lines placed. Blood products and antibiotics were employed based on the clinical setting, according to hospital practice guidelines. The indwelling central venous access devices used in this study included 7 Fr and 9 Fr double lumen Hickman lines (Bard Medical, Covington, GA), and 5.8 Fr and 7.8 Fr single lumen Port-a-caths (Deltec, Smiths Medical, Dublin, OH). Trainees were already versed in the surface landmark technique prior to their entry to the study; the bony landmark technique was taught to trainees intra-operatively, by directly indicating the bony landmarks on patients on the operating table.

For the surface landmark method taught in the first study period, the skin is punctured with the introducer needle within the delto-pectoral triangle, identified either as a point 1-cm inferior to the junction of the medial one-third and lateral two-thirds of the clavicle, or as the point at which the anterior convexity of the medial clavicle transitions into an anterior concavity laterally (Fig. 1a) [7, 9]. Once the skin is breached, the needle is directed posterior to the clavicle and aimed at a point just above the sternal

notch or the apex of the delto-pectoral triangle, until the SCV is entered.

For the bony landmark method taught in the second study period, the path of the needle and its point of entry to the SCV is first visualized—in a coronal and an axial plane. First, the course of the SCV in the coronal plane (*X*/*Y*-axis) is mapped to a line joining the inferior point of the coracoid process and the superior point of Halsted's ligament, just behind the subclavius muscle (Fig. 1b, upper panel—coronal plane). The latter is identified at the site between the first rib and the head of the clavicle at the sternoclavicular junction and can be palpated as an area of firmness especially in thin patients. Next, the depth of the SCV in the axial plane (*Z*-axis) is estimated according to the depth of the jugulo-venous pulse below the level of the anterior chest wall (Fig. 1b, lower panel—axial plane). The trainee thus visualizes the anticipated path of the needle and point of entry to the medial SCV in 3 dimensions using these landmarks. He/she enters an appropriate point in the infraclavicular skin along this line mapping the expected course of the SCV in the coronal plane (*X*/*Y*-axis) and directs the needle posterior to the clavicle to the required depth in the axial plane (*Z*-axis), which is typically at an angle of 30° to the horizontal.

Data and analysis

The categorical variables analyzed in this study were gender, previous insertion of a central venous access device, diagnosis, on-going chemotherapy, seniority of the first surgeon performing the procedure, side of SCV punctured, preoperative infection, and prior or preoperative sepsis. The continuous variables analyzed were age of the patients, hemoglobin level, white cell count and platelet count immediately prior to procedure, and number of cycles of on-going chemotherapy if present. The outcome measures evaluated were: number of attempts required for successful SCV cannulation (number of forward-reverse passes made), duration of the procedure (from "skin to skin"), and intra- and post-procedural complications (subcutaneous hematoma, pneumothoraxes, intrapleural catheter, distortion and rupture of the catheter, and catheter migration into the jugular vein, superior vena cava, and heart cavities). Data were analyzed using SPSS v.19.0 (IBM, New York, NY). Patients' characteristics and procedural variables were compared between the two study periods and for cases performed by consultants versus trainees. Chi-square test or Fisher exact test were used for categorical variables. Two-sided independent two-sample *T* test or nonparametric Mann–Whitney *U* test were performed for continuous variables depending on whether the normality assumption was tenable. Statistical significance was set at $P \leq 0.05$.

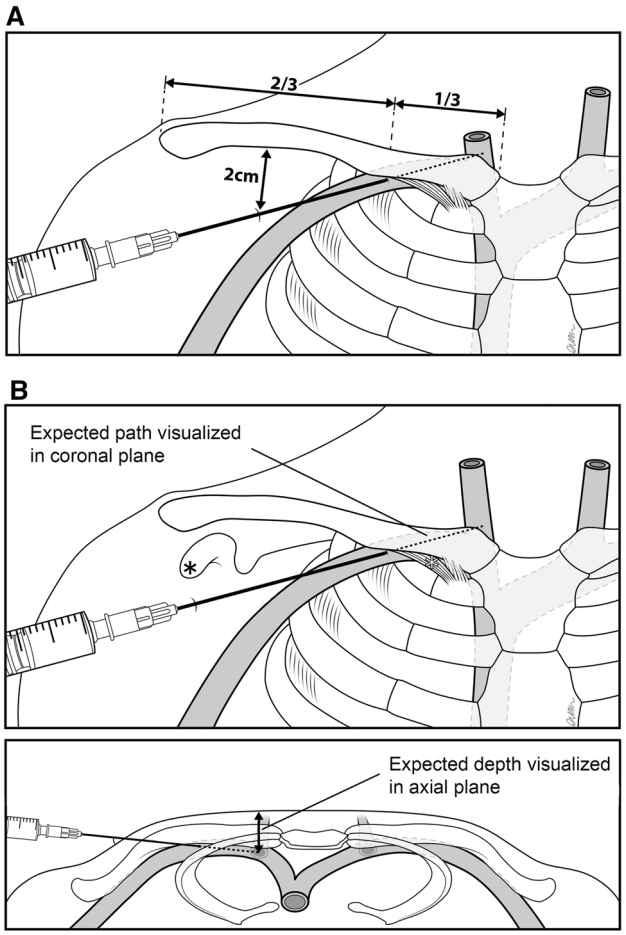

Fig. 1 Schematic illustration of approach to the right subclavian vein using the surface landmark-based approach (**a**) and the bony landmark-based approach (**b**), demonstrating the respective skin and vein entry points. For the bony landmark method, the path of the needle is based on the expected course of the SCV as visualized in 3 dimensions. Its course in the coronal plane is mapped on a line joining the coracoid process (dark asterisk) and the Halsted ligament (light asterisk) (**b**, upper panel); its depth is mapped in the axial plane based on the depth of the jugulo-venous pulse below the level of the anterior chest wall (double arrow) (**b**, lower panel)

Results

In total 271 cases were included in this study, with 103 and 168 cases in study periods 1 and 2, respectively; 168 (62%) were male and 103 (38%) were female, and mean age was 6 ± 5 years. The proportion of cases performed by trainees was similar in both study periods: 52 of 103 (50.5%) and 92 of 168 (54.8%) in study periods 1 and 2, respectively (Fig. 2). In the first study period, 9 trainees performed a mean of 5.8 (S.D. ± 4.3) cases as first surgeon, and in the second period, 8 trainees performed a mean of 11.5 (S.D. ± 17.0) cases as first surgeon. Five trainees operated on cases in both study periods.

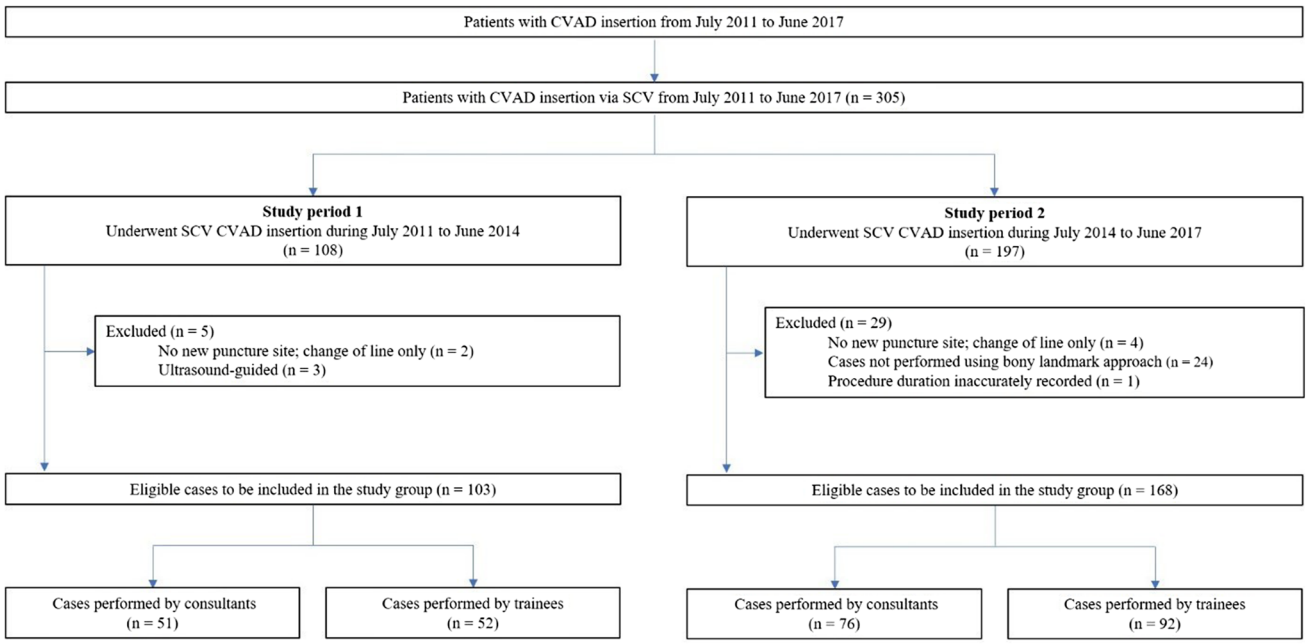

Fig. 2 CONSORT diagram illustrating patient and surgeon subgroups in study periods 1 and 2. CVAD: central venous access device; *SCV* subclavian vein

When comparing all cases in study periods 1 and 2 (to establish their baseline equivalence), the following patient and procedural variables differed significantly: treatment with chemotherapy prior to procedure ($P = 0.004$), number of cycles of chemotherapy prior to procedure ($P = 0.008$), side of vein used ($P < 0.001$), preoperative fevers ($P = 0.026$), and age of patients at time of procedure ($P = 0.041$) (Table 1).

When comparing only cases performed by trainees in study periods 1 and 2, these variables did not differ, and instead side of vein used and patient age were significantly different. Comparing study period 2 to study period 1, the left SCV was more frequently used for catheterization (82.6% and 38.5%, respectively, $P < 0.001$) and patients were younger (5.96 and 8.67 years, respectively, $P = 0.003$). Procedural duration was shorter (42.5 and 58.3 min, respectively, $P < 0.001$), but mean number of attempts at catheterizing the SCV did not differ significantly between study periods 2 and 1 (2.0 and 1.8, respectively, $P = 0.257$). There were two cases (3.8%) of postoperative complication in study period 1 and five cases (5.4%) in study period 2 ($P = 1.000$) (Table 2).

The two cases of complications when surface landmark method was used were excoriation around the puncture site that was treated with tetracycline ointment and kinking of the sheath likely secondary to hitting the first rib and clavicle during initial insertion. The five cases of complications when bony landmark method was adopted were temporary Horner's syndrome, port site hematoma, port site ulceration, misdirection of guidewire into the internal jugular vein requiring readjustment, and migration of Hickman line cuff requiring change of line.

Discussion

We described and evaluated a novel method for teaching percutaneous SCV catheterization using bony landmarks to enhance three-dimensional visualization of structures. We found that the new teaching method was associated with shorter procedural time despite trainees operating on younger patients, without impacting complication rates and number of attempts at catheterizing the vein. Indeed, safety considerations need to be paramount in the evaluation of a new teaching method for a surgical procedure.

While central venous catheterization provides a safe and appropriate access to the venous system for central venous monitoring and large fluid administration [2, 3, 8, 10], it is associated with complications that are both dangerous and costly to manage—mechanical (5–19%), infectious (5–26%), and thrombotic (2–26%), regardless of approach [11]. The SCV approach is widely practiced, but incidence of procedural complications can range variably from 3 to 34%, and is influenced by patient's body habitus, age, and clinician's experience [12, 13]. SCV catheterization carries the lowest risk for infectious and thrombotic complications

Table 1 Comparison of patient characteristics and procedural variables for all cases performed in study periods 1 and 2 (n = 271)

Variables	Study period 1 (n = 103)		Study period 2 (n = 168)		P value*
Categorical variables	n	%	n	%	
Gender					0.305
Male	68	66.0	100	59.5	
Female	35	34.0	68	40.5	
Previous CVAD	21	20.4	25	14.9	0.248
Disease type					0.787
Hematological malignancies	53	51.5	81	48.2	
Intracranial malignancies and retinoblastoma	16	15.5	24	14.3	
Solid extracranial malignancies	29	28.1	50	29.8	
Non-malignant conditions	5	4.9	13	7.7	
Undergoing chemotherapy	49	47.6	50	29.8	0.004
Type of CVAD					0.688
Port-a-cath	72	69.9	113	67.3	
Hickman line	31	30.1	55	32.7	
First surgeon rank					0.532
Consultant	51	49.5	76	45.2	
Trainee	52	50.5	92	54.8	
Vein used					0.000
Right	63	61.2	38	22.6	
Left	40	38.8	130	77.4	
Preoperative fever	12	11.7	7	4.2	0.026
Preoperative sepsis	5	4.9	5	3.0	0.512
Continuous variables	Mean	SD	Mean	SD	P value*
Age	7.67	5.29	6.39	4.78	0.041
No. of cycles of recent chemotherapy prior to procedure	1.27	2.28	0.66	1.47	0.008
Blood test results prior to procedure					
Hemoglobin (g/dL)	10.94	1.93	10.69	1.67	0.260
White cell count ($\times 10^9$)	7.82	8.20	8.08	6.32	0.774
Platelet count ($\times 10^9$)	241.22	189.58	288.38	195.02	0.052
Catheter size used (Fr)	6.70	1.19	6.71	1.14	0.978

CVAD central venous access device, *SD* standard deviation

*Chi-square test or Fisher exact test for categorical variables; Two-sided independent two-sample T test or Mann–Whitney U test for continuous variables

and the lowest risk for arterial puncture [11], but the highest risk for pneumothorax, hemothorax, and chylothorax particularly on the left, and catheter tip misplacement particularly on the right, with these risks being independent of patient's age [11, 14, 15]. Principally, we found our new approach to be safe even when taught to multiple trainees on patients of varying ages.

We hypothesize that the key benefit of the new approach is improved mental visualization of the venous anatomy and its relationship and interaction with surrounding structures. The goal in SCV cannulation is to guide the needle deep to the clavicle, superior to the first rib, and to enter the subclavian vein as it courses over the first rib, while avoiding accidental injury to surrounding structures. Thus, to minimize complications and improve consistency and reproducibility, classic teaching methods have used surface anatomical landmarks to help the operating surgeon orient the deep course of the cannulating needle as it approaches the SCV. However, a study of SCV cannulations performed by residents showed that the commonest technical errors were still related to anatomic considerations [16]. Cutaneous punctures were often made too close to the clavicle—less than 1 cm away, in adults—causing the needle to miss the vein underneath it. Needles were inserted through the clavicular periosteum often due to attempts to "walk" down the side of the clavicle [17].

Table 2 Comparison of patient characteristics and procedural outcomes for cases performed by trainees only in study periods 1 and 2 (n = 144)

Variables	Study period 1 (n = 52)		Study period 2 (n = 92)		P value*
Categorical variables	n	%	n	%	
Gender					0.705
Male	38	73.1	63	68.5	
Female	14	26.9	29	31.5	
Previous CVAD	6	11.5	13	14.1	0.800
Disease type					0.748
Hematological malignancies	29	55.8	47	51.1	
Intracranial malignancies and retinoblastoma	6	11.5	17	18.5	
Solid extracranial malignancies	13	25.0	22	23.9	
Non-malignant conditions	4	7.7	6	6.5	
Undergoing chemotherapy	21	40.4	29	31.5	0.362
Type of CVAD					0.702
Port-a-cath	36	69.2	67	72.8	
Hickman line	16	30.8	25	27.2	
Vein used					0.000
Right	32	61.5	16	17.4	
Left	20	38.5	76	82.6	
Preoperative fever	6	11.5	5	5.4	0.205
Preoperative sepsis	2	3.8	4	4.3	1.000
Postoperation complications	2	3.8	5	5.4	1.000
Continuous variables	Mean	SD	Mean	SD	P value*
Age	8.67	5.54	5.96	4.89	0.003
No. of cycles of recent chemotherapy prior to procedure	0.87	1.69	0.67	1.48	0.480
Blood test results prior to procedure					
Hemoglobin (g/dL)	10.40	2.00	10.71	1.72	0.341
White cell count ($\times 10^9$)	7.65	6.59	8.14	6.63	0.670
Platelet count ($\times 10^9$)	224.83	170.67	282.90	205.65	0.086
Catheter size used (Fr)	6.90	1.25	6.56	1.05	0.082
No. of attempts	1.75	1.33	2.04	1.57	0.257
Duration of procedure (minutes)	58.27	16.20	42.52	13.22	0.000

CVAD central venous access device, *SD* standard deviation

*Chi-square test or Fisher exact test for categorical variables; Two-sided independent two-sample T test or Mann–Whitney U test for continuous variables

After passing posterior to the clavicle, trajectories (in the Z-axis) were too shallow, causing the needle to only nick the vein anteriorly [18], or needles were aimed too cephalad [19, 20]. Also, anatomic surface landmarks were improperly or inadequately identified. Taken together, these errors suggest that trainees lack three-dimensional perception of the position of the SCV in relation to the surrounding osseous anatomy and have uncertainty about the position of the underlying pleura in space leading to over compensation in the X/Y and Z-axes to avoid it. Furthermore, if these errors occurred in teaching SCV cannulation in adults where anatomical dimensions are largely similar, one must consider the additional dynamic of teaching SCV cannulation in the pediatric patient population where the range of body sizes is far more varied.

Another anatomical consideration that could affect the rate of successful SCV cannulation using the classic approach is the fact that surface landmarks are all determined in relation to the clavicle—which can move independent of the SCV, and can change its position and angle relative to the SCV with posture and age (the SCV is located more cephalad in neonates and becomes more caudal with age [7]. Changes in the relationship of the SCV and the clavicle are not taken into consideration with the surface landmark approach. Ease of cannulating the SCV is increased when the SCV and clavicle are more closely

approximated and more closely aligned, and over a longer length [7]. However, with elevation of the shoulders, the angle between the SCV and clavicle increases and so a smaller length of the SCV is overlapped by the clavicle, making cannulation more difficult [7]. Indeed, randomized trials based on this principle have shown equally increased success in SCV cannulation with neutral or depressed shoulder positions, compared to elevation [21–23]. Another critical factor affecting successful SCV cannulation is the size of the thoracic inlet, which is related to the inner margin of the first rib and the lateral margin of the manubrium—a landmark not considered in the classic approach [24]. Hence, we suspect that the bony landmarks of the coracoid process and Halsted ligament may more consistently approximate the true path of the SCV. These bony structures will move correspondingly in relation to changes in shoulder position and may also provide a better indication of the true location of the SCV at the thoracic inlet. However, this theory needs to be proven more definitively with cadaveric or anatomical cross-sectional imaging studies.

The study was limited by the small number of trainees assessed, and variations in patient characteristics between study subgroups. However, when comparing cases operated on by trainees versus consultants, differences in patient profiles were limited to variables such as preoperative hemoglobin, gender, and prior CVAD placement, which would have presumably less impact on selection bias. When selecting for cases performed by trainees, only 2 variables differed—side of vein and patient age. These were also unlikely to have substantially affected the final study outcome as the new teaching method was instead associated with shorter procedural times despite being used on younger patients, with no statistically significant difference in the number of attempts at vein cannulation. Experience and confidence gained by trainees over time could have biased results, especially with trainees who were involved in both cohorts, but this number was small. We were also unable to study the relationship of anthropometric parameters due to lack of this data.

While the shorter operative times with the new approach may suggest more accurate attempts at SCV cannulation, this study was unable to specifically relate this to better mental visualization of the venous anatomy and its relationship and interaction with surrounding structures. In future more intuitive evaluation of trainees will be required to better understand how the different approaches change their perceptions and decision-making processes. Also, our study only studied SCV cannulation. While the SCV is our preferred route of access, opinions differ on the relative benefits of this versus the internal jugular vein, and fair comparisons of the relative risks and benefits of either route are lacking [11, 25]. Some authors purport that the amenability of internal jugular access to ultrasound-guided puncture makes this approach safer compared to landmark-guided SCV cannulation, but this also remains unproven [26]. Other technical factors such as variations in head position and use of a roll between the shoulders further influence the diameter of the SCV, and therefore the success of SCV cannulation, particularly in children, and could have been a confounder to our study [27–29]. However, we noted minimal differences in patient positioning preferences between surgeons in our unit.

Conclusions

With a novel bony landmark-based approach for teaching SCV cannulation, the duration of procedures performed by trainees was shorter without impacting the number of cannulation attempts. Bony landmarks may better approximate SCV position across a range of patient ages; thus, the new approach may provide better three-dimensional visualization of the venous anatomy and surrounding structures, and so improve the consistency of SCV cannulation in CVAD placements in children.

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