Simple formulas to determine optimal subclavian central venous catheter tip placement in infants and children

Andrea Stroud a,c, Jill Zalieckas a,d, Corinne Tan a,e, Sarah Tracy b,f, David Zurakowski b,e, David P. Mooney a,d,*

a Department of Surgery, Dartmouth-Hitchcock Medical Center and the University of Massachusetts School of Medicine
b Boston Children’s Hospital and the University of Massachusetts School of Medicine
c Department of Surgery, Dartmouth-Hitchcock Medical Center and Dartmouth Medical School
d Boston Children’s Hospital

Abstract

Background/Purpose: Optimal central venous catheter (CVC) tip location is necessary to decrease the incidence of complications related to their use. We sought to create a practical method to reliably predict the length of catheter to insert into the subclavian vein during CVC placement in children.

Methods: We performed a retrospective review of 727 chest radiographs of children who underwent either left or right subclavian CVC placement. We measured the distance from the subclavian entry site to the right atrium/superior vena cava (RA/SVC) junction, following the catheter’s course. We analyzed the relationship between that length and patient characteristics, including: age, gender, height, weight and body surface area (BSA).

Results: Two derived formulas using the BSA best correlated with the optimal subclavian CVC length. For the left subclavian vein approach, the optimal catheter length was 6.5*BSA + 7 cm, and for the right subclavian vein approach it was 5*BSA + 6. The use of these formulas correlated in CVC tip placement in a clinically proper location in 92.9% of smaller children and in 95.7% of larger children.

Conclusion: The optimal length of central venous catheter to insert into the subclavian vein may be determined through the use of a simple formula using the BSA.

© 2014 Elsevier Inc. All rights reserved.

Central venous access in children is obtained for a variety of reasons including, but not limited to: infusion of parenteral nutrition, chemotherapy, and vasoactive medications, hemodynamic monitoring, and to ensure vascular access. To obtain central venous access, especially for long term need, the subclavian vein is commonly used. With the standard Seldinger technique [1], once the subclavian vein has been accessed with a guide wire, the length of catheter tubing to insert into the vein in order to position the catheter tip at the junction of the right atrium and superior vena cava (RA/SVC junction) must be determined. Positioning the catheter tip at the RA/SVC junction decreases the rate of complications such as superior vena cava thrombosis, dysrhythmias and the rare cases of great vein and cardiac puncture resulting in tamponade [2,3]. Additionally, the intra-operative insertion of an incorrect length of catheter may lead to removal and replacement or revision of the catheter, increasing the possibility of intra-operative or postoperative complications, prolonging the operative time, and increasing equipment expenses. The technique used to determine the proper catheter length must be simple to use and easy to remember.

1. Methods

We performed a retrospective review of 727 consecutive children, who underwent central venous catheter placement, by either the left (514) or right (213) subclavian vein approach, between January 1, 2005 and June 6, 2008, using a departmental billing database. Fourteen different pediatric general surgeons, all experienced in subclavian central venous line placement, placed approximately 50 catheters each. Given the retrospective nature of this study, it was not possible to determine how many times the line had to be repositioned or replaced in the operating room. In all cases, central venous access was gained in the right or left subclavian vein using an infraclavicular approach. The subclavian vein was accessed percutaneously using a finder needle and then dilated over a guidewire using the Seldinger technique. There was no attempt at standardization of the procedure and the appropriate length of catheter was chosen on an individual basis by each surgeon. Each patient had an upright, anterior-posterior chest radiograph taken immediately following the procedure in the post-anesthesia care unit.

Patient demographics including age, gender, height and weight were collected. Body surface area (BSA) was determined and
To determine the proper CVC length, we retrospectively reviewed the post-procedure chest radiographs. Using the free-hand ruler function on an electronic film viewing system (Synapse Fujifilm, Tokyo, Japan), we measured the length of catheter, following the course of the catheter, from the subclavian vein entry site, determined by the location of the change in direction of the catheter tubing from superiorly to transversely, to the RA/SVC junction (determined by a rounded broadening of the right mediastinal margin). To obtain this measurement we followed the course of the catheter tubing, but it was independent of the location of the actual tip of the catheter. In order to take into account variations in the location of the RA/SVC junction based upon the radiographic technique, the radiographic measurement was adjusted for the degree of inspiration on the film according to the formula: adjusted length (cm) = measured length (cm) + (9 minus the rib number noted at the top of right diaphragm). For example, if the distance from the subclavian vein entry site to the RA/SVC junction was measured as 11 cm and the apex of the right diaphragm was at the 7th rib, the adjusted length would be 11 + (9-7) = 11 + 2 = 13 cm.

In order to determine the range of clinically acceptable distance away from the RA/SVC junction that would be considered proper CVC tip placement, we reviewed 200 randomly chosen radiographs blinded to the patients’ BSA and optimal line length. The most superior position above and the most inferior position below the RA/SVC junction on the radiograph that would be considered clinically acceptable CVC tip placement were determined. This range was defined anatomically as lying within the mid–superior vena cava to the upper right atrium. The distance between these two points was measured using the ruler function on an electronic film viewing system (Synapse Fujifilm, Tokyo, Japan). The measured length was then divided by 2, resulting in the maximally acceptable distance away from the RA/SVC junction for CVC tip placement. These values (i.e. maximally acceptable distances) were then evaluated across the range of BSA’s. The percentage of patients whose CVC tip placement would have been within an acceptable distance from the RA/SVC junction through the use of the derived predictive formulas was determined for smaller children (BSA of less than 0.5 and in 95.7% of children with a BSA greater than 0.5).

1.1. Statistical analysis

The adjusted optimal CVC length was then analyzed to determine the best fitting relationship by considering gender, age, height, weight, and BSA as separate predictor variables. Several linear and nonlinear regression models were explored using R2 as the criterion for best fit. Multivariate analysis was also performed to assess whether there were gender differences and to identify if a combination of predictor variables improved estimation of true catheter length. The absolute difference between observed and predicted length and average percent error were used to summarize the precision of the prediction model. For predicted CVC length, a 95% prediction interval was constructed to provide a range of measurements around the optimal length for both left and right sides. Statistical analysis was performed using the SPSS software package (version 16.0, SPSS Inc., Chicago, IL). Two-tailed values of P < 0.05 were used to indicate statistical significance. This study was approved by the Boston Children’s Hospital Committee for Clinical Investigation (IRB) ID number: M07-07-0284.

2. Results

Our study population ranged from 0.21 to 21.9 years of age with a mean age of 8.7 ± 6 years (Table 1). Weight ranged from 3.2 to 126.9 kilograms with a mean of 33.6 ± 23.7 kg, height from 37 to 194 cm with a mean of 124.1 ± 36.1 cm and BSA from 0.21 to 2.46 m² with a mean value of 1.05 ± 0.51 m². There were 397 boys and 330 girls, 514 of whom underwent left subclavian CVC insertion and 213 right subclavian CVC insertion. There were no significant differences in optimal CVC length identified between males and females (P > 0.20).

BSA was a highly significant predictor of optimal CVC length for both left and right-sided catheters (P < 0.001) using linear regression (R2 = 0.89, R2 = 0.88, Figs. 1 and 2). As expected, multivariate analysis revealed that optimal CVC lengths were significantly longer for left-sided catheters than right (P < .0001). Several nonlinear models including quadratic, cubic, and power functions were compared and resulting R2 values that were not higher than a simple linear equation. Gender, weight, and height provided no significant improvement in the accuracy of estimating the actual CVC length (all P > .05). The linear prediction equations for determining the optimal CVC length are:

Optimal length of left subclavian CVC = (6.5 × BSA) + 7 cm
Optimal length of right subclavian CVC = (5 × BSA) + 6 cm

The data are plotted in a scatter diagram for left and right groups as shown (Figs. 1 and 2).

Using 200 randomly selected study radiographs, we determined the range of clinically acceptable distance from the RA/SVC junction for the CVC tip. This distance varied from 1.1 to 4.3 cm and correlated directly with the BSA (ρ = 0.81), which varied from 0.21 to 2.44 (Fig. 3).

Using these derived prediction formulas to determine optimal CVC length resulted in CVC tip placement within the clinically acceptable maximal distance away from the RA/SVC junction in 92.9% of children with a BSA less than 0.5 and in 95.7% of children with a BSA greater than 0.5.

### Table 1

| Study patient characteristics of 727 patients who underwent central venous catheter placement by either the left or right subclavian vein approach. |
|-----------------|-----------------|-----------------|-----------------|
| Age (years)     | Weight (kg)     | Height (cm)     | BSA (m²)        |
| Range           | 0.21 to 21.9    | 3.2 to 126.9    | 37 to 194       | 0.21 to 2.46    |
| Mean            | 8.7             | 33.6            | 124.1           | 1.05            |
| STD             | 6.0             | 23.7            | 36.1            | 0.51            |

kg = kilograms, cm = centimeters, BSA = Body Surface Area, m² = meter squared, STD = standard deviation.
Determining the optimal central venous catheter insertion length via the subclavian approach would seem to be a simple maneuver, but is often fraught with error in children. Optimal tip positioning at the RA/SVC junction is vital to decrease the risk of cardiac arrhythmias, thrombosis secondary to endothelial damage, perforations, as well as to ensure optimal CVC function. The intraoperative insertion of the wrong length of catheter may lead to catheter removal and replacement, which may increase the intraoperative complication rate, prolong the procedure, and increase equipment costs, in children.

Topographic techniques have been devised to determine optimal CVC insertion lengths. Na et al. used the sternal head of the right clavicle and the nipple line as anatomical landmarks to estimate the ideal IJ CVC length in the pediatric population [5]. Kim KO et al. measured the distance between the skin puncture site and the right third intercostal space in children who were undergoing IJ CVC placement for congenital heart surgery [6]. They found that inserting the catheter at this measured length resulted in 98.8% of the catheter tips being located in the desired site above the RA. Kim MC et al. determined CVC length by placing the catheter over patients’ skin from the needle insertion point through the ipsilateral clavicular notch, and to the insertion point of the second right costal cartilage to the sternomanubrial joint [7]. They found this to result in accurate placement in 200 adults undergoing CVC placements by either the subclavian or IJ vein.

Other authors have described using preoperative imaging to determine proper CVC length. Lee and Lee measured the distance from the edge of the right transverse process of the first thoracic vertebra to the carina on pre-procedure chest radiographs in adults and found that this provided a good estimate for the proper right IJ CVC length [8]. Ryu et al. reviewed 100 right subclavian and IJ adult CVC placements and found the sum of the distance from the needle insertion point to the suprasternal notch and the distance from the suprasternal notch to the carina on a pre-procedure chest radiograph was the optimal CVC length [9]. After reviewing 119 right IJ and subclavian CVC placements in adults, Uchida et al. concluded that the appropriate CVC length could be estimated by the sum of half the length of the right clavicle and the vertical distance from the sternal head of the right clavicle to the carina on chest radiograph [10].

Intraoperative imaging techniques have also been used to determine the optimal CVC length. Andropoulos studied the use of intraoperative transesophageal echocardiography to guide CVC tip placement via the IJ, subclavian and external jugular routes in children and found it to be very accurate [11]. In a prospective, randomized study in adults published in 1993, McGee also found echocardiography valuable to determine optimal CVC placement [2]. In 1985, Serafini et al. described using endocardiac ECGraphy where the P wave deflection indicates proper positioning of the CVC tip at the sinus node level [12]. Hayashi et al. used central venous pressure waveforms to guide CVC placement and found wide variation when using that technique alone [13]. Lein BC et al. describe a technique using fluoroscopic guidance to achieve proper CVC position [14]. Intraoperative fluoroscopy is used to position the guidewire at the SVC-RA junction, and the length of guidewire left outside the patient is measured and subtracted from the total guidewire length, thus calculating the appropriate catheter length. Similarly, Janik JE et al. reported a half the rate of misplaced central venous catheters when intraoperative fluoroscopy was used compared using only postoperative chest x-ray (4.1-4.9% vs 9.4%) [15]. While many of these technologies may prove beneficial, their use would increase the complexity and expense of the procedure beyond any benefit that would be obtained.

Previous investigators have devised formulas for optimal CVC length using body morphology. Andropoulos devised formulas using height and weight to determine the optimal length of CVC placement for both the right IJ and right subclavian vein [16]. Unfortunately, seventy two percent of the 456 catheter placements used in their study were inserted into the right IJ and data for both veins was combined in their analysis. Therefore, their formula is less reliable for the accurate determination of subclavian placement. Hayashi et al. reviewed 158 children who weighed less than 20 kg who were undergoing cardiovascular surgery and found a correlation between the optimal length of right IJ CVC catheters and the patient’s height [13]. Yoon et al. utilized transesophageal echocardiography, in children with heights between 40 and 140 cm who were undergoing congenital heart surgery, to identify optimal CVC tip position [17]. The measured catheter lengths used for right IJ CVC placement were subsequently found to correlate with the patients’ heights.

For various reasons, including patient comfort and ease of placement, the subclavian vein is a common approach for surgical CVC insertion in children. This study looked exclusively at the infraclavicular subclavian approach and used the BSA to calculate the catheter length required for optimal CVC tip position. Analyzing height and weight separately, the BSA, which utilizes both variables, was more accurate than either alone. With electronic medical record systems, the BSA is now readily available to clinicians and rarely needs to be calculated de novo. This method does not require preoperative or intraoperative imaging or specialized equipment and the formulas
are easy to recall and simple to use. They result in CVC tip placement in a clinically proper location in 92.9% of smaller children and in 95.7% of larger children, and may be readily translated to subclavian catheter placements in non-operating room settings.

An important limitation of our study is that children weighing less than 3.2 kg were not included in our dataset, as the subclavian vein was used infrequently for access in these smallest patients. Further, we determined that our prediction formula was less accurate in patients with a BSA < 0.5 when compared to larger children. Therefore, we recommend using caution when applying our formula in children less than 3.2 kg. Kim JH et al. provide a suggested right subclavian central catheter length, based on height and weight, in children weighing less than 5 kg [18]. We aim to include an evaluation of this population in a future prospective trial.

Another important limitation of this study is that the surgical technique was not controlled for and this may introduce bias into our analysis. In our analysis of 200 randomly selected radiographs the range of appropriate catheter tip position ranged from 1.1 to 4.3 cm. We expect that variations in surgical technique are unlikely to result in differences greater than 1 cm in the smallest patients or more than 3–4 cm in the largest children. Therefore, despite differences in individual surgical technique, when standard landmarks are used, our formulas should result in accurate catheter tip position.

4. Conclusions

We have devised two simple to use formulas that estimate the optimal length of CVC to insert into either subclavian vein to obtain proper catheter tip position in over 92% of smaller children and over 95% of larger children. The use of these formulas should provide improved efficiency and accuracy in subclavian venous catheter placement and decrease the rate of catheter malposition and its associated complications and inefficiencies. In the future, we plan to evaluate the application of these formulas in a prospective trial.

References