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Predicting the optimal depth of ultrasound-guided right internal jugular vein central venous catheters in neonates

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ABSTRACT

Background: Poor positioning of a central venous catheter (CVC) can cause severe complications. The objective is to create a formula that predicts the optimal insertion depth of a real time ultrasound-guided CVC in the right internal jugular vein (RIJV) in newborns.
Methods: Between 2015 and 2017, 91 newborns that required a CVC were included in a prospective observational study. Variables such as gestational age, gender, weight, height, and neck length were studied. On the chest x-ray, the distance between the insertion site on the skin and the catheter tip was measured.
Results: Of the patients included, 50 (54.9%) were males and 40 (44.4%) females; 64 (70.3%) were preterm. Mean gestational age was 33.44 (25 to 41) weeks, weight 2020 (580 to 3980) g, and height 43.04 (26 to 53) cm. Variables were correlated with catheter length and an algorithm was modeled for the introduction method, in which the highest corrected determination coefficient was obtained for weight ($R^2 = 0.723$).
Conclusion: This study demonstrated that the weight of the newborn was the most significant individual predictor of optimal insertion depth of a CVC in the RIJV. The formula $Y = 2.6 + 0.7$ (weight in kg) that we suggest is practical and reproducible.
Level of evidence: Level IV.

Poor positioning of a central venous catheter (CVC) can cause complications, such as arrhythmias, pericardial tamponade, and mediastinal effusions, that can affect newborn stability and carry an increased risk of mortality [1,2]. It is known that optimal location of the CVC tip is within the superior vena cava (SVC), just above the entrance to the right atrium (RA) [3]. However, the position of the CVC is usually not evaluated until a postprocedural chest x-ray is done [4]. Despite several formulas and graphs, using different body measurements, that have been proposed to predict the correct position of central catheters, none of these have been validated in neonatology [5–8].

Choi et al. [9] conducted a study in 92 pediatric patients who required a CVC in the internal jugular vein. They performed a linear regression model to correlate weight, height, and age with the optimal depth of the catheter in order to predict the insertion depth prior to the procedure to thereby reduce repositioning and complications associated with CVC misplacement. They found height as predictor of CVC depth, and published a formula to calculate optimal depth in the left and right IJV. However, their model is not specific for neonatal patients.

The aim of this study was to design a formula that predicts the optimal insertion depth of an ultrasound-guided CVC in the right internal jugular vein (RIJV) in neonates.

1. Materials and methods

Between August 2015 and October 2017, neonates hospitalized in the Neonatal Intensive Care Unit (NICU) of the "Dr. José Eleuterio González" University Hospital of the Universidad Autónoma de Nuevo León in Monterrey, Mexico were prospectively included in this observational study.

We excluded patients in whom the measurement variables were not obtained prior to CVC placement, patients with lesions at the insertion site, or patients with grade 2, 3, and 4 intraventricular hemorrhage; patients transferred to another hospital or those with incomplete anthropometric or demographic data were eliminated.

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The neonates were classified according to their weight, following the World Health Organization classification, as appropriate for gestational age (AGA, ≥2500 g), low birth weight (LBW <2500 g), very low birth weight (VLBW <1500 g) and extremely low birth weight (ELBW <1000 g).

All patients in whom the clinician decided to place a CVC in the RIJV as part of their treatment were included in the study. All of the catheters used were 4 Fr, double lumen and 13 cm in length. Procedures were performed by the same pediatric surgeon; a puncture was made with real-time ultrasound (US) guidance using the EDGE (SonoSite FujiFilm Inc., Bothell, WA, USA) portable ultrasound with a 7–13 MHz hockey stick transducer to increase the efficacy of the procedure and to reduce the risk of complications [10,11].

Variables such as gestational age, gender, diagnosis, weight, height, and length of the neck were studied. The distance between the mastoid and the xiphoid process was taken as a reference of CVC insertion depth. Prior to CVC insertion, the diameter of the RIJV during inspiration was measured by US (short axis) at the cricoid cartilage level. Distance from the skin to the anterior wall of the RIJV and the anatomical relationship between the RIJV and the carotid, as previously published [12], were measured.

All procedures were performed in the NICU to ensure close monitoring of vital signs. Midazolam (100 μg/kg IV) and/or ketamine (1–2 mg/kg IV) were used for sedation and lidocaine for local analgesia. The patients were placed in the supine position with the head rotated 40° towards the opposite side of the puncture site. The needle puncture

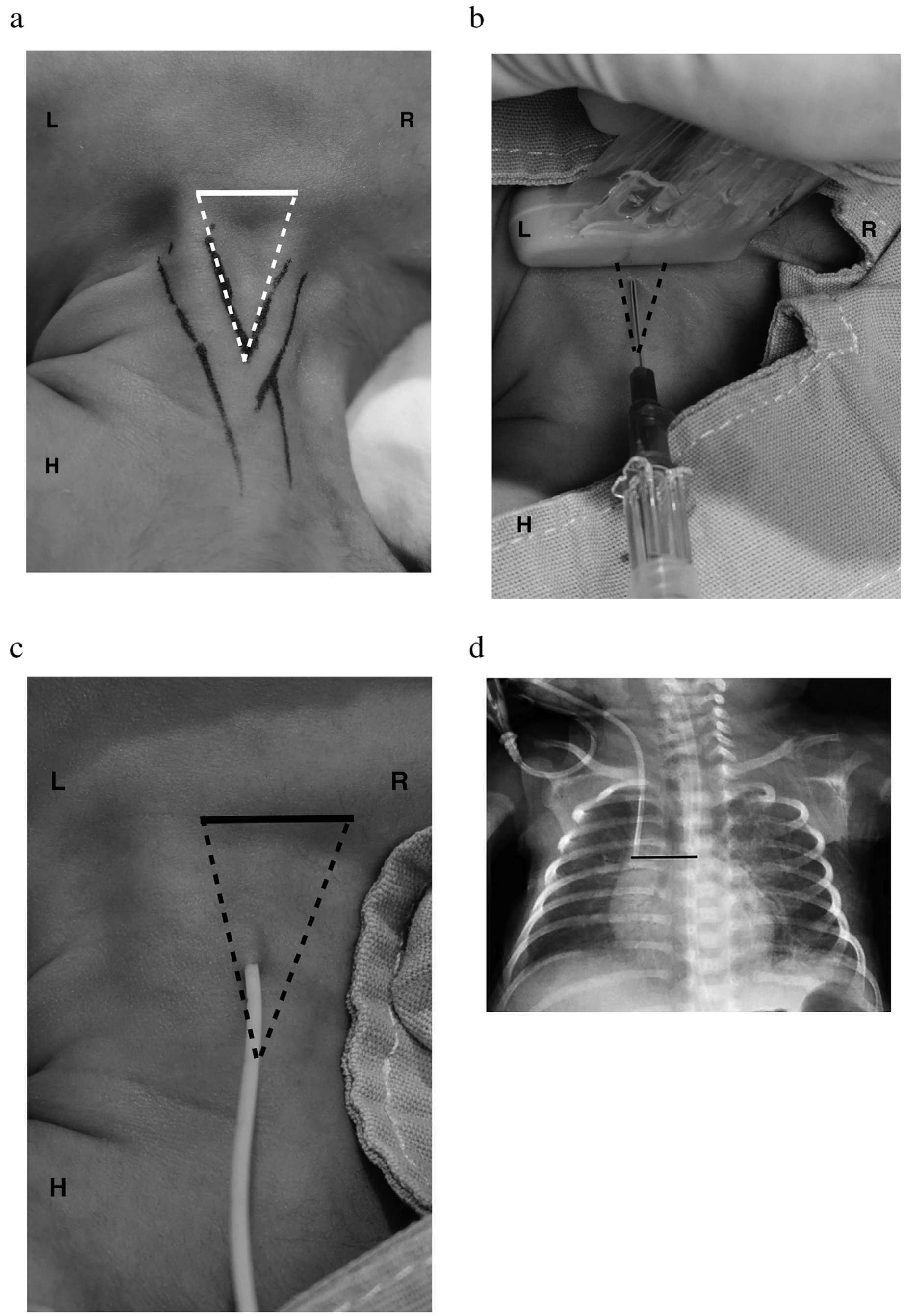

Fig. 1. (a) Sedillot's triangle, the sternal head of the sternocleidomastoid muscle medially (dotted line to the patient left), the clavicular head of the sternocleidomastoid laterally (dotted line to the patient right), and the superior border of the medial third of the clavicle inferiorly (line). H: head, R: patient right and L: patient left. (b) The needle puncture was performed in real-time US guidance in short-axis at the apex of the Sedillot's triangle. H: head, R: patient right and L: patient left. (c) Catheter in the apex of the Sedillot's triangle. H: head, R: patient right and L: patient left. (d) Chest x-ray of catheter in adequate position is shown using the carina as an anatomical reference (horizontal line).

was performed in real-time US guidance in short-axis at the apex of the triangle formed by the sternal and clavicular head of the sternocleidomastoid muscle with the clavicle as the base (Sedillot's triangle Fig. 1a) (Fig. 1b and Fig. 1c). In our hospital, the depth of the CVC to be introduced is routinely chosen based on the experience of the surgeon or taking as a reference the distance between the puncture site and the inter-nipple line. After placement of the CVC, a chest x-ray was taken to evaluate the location of the tip and rule out possible complications.

1.1. Optimal insertion length estimation

On the chest x-ray of each patient, the distance between the insertion site and the catheter tip was measured using the radiology information system (RIS) in conjunction with picture archiving and communication system (PACS). To determine the optimal position of the CVC, the carina was taken as an anatomical reference point, since it has been described that it is discretely cephalic to the junction between the superior vena cava and the RA; besides, it is easily identifiable on chest x-rays [13] (Fig. 1d).

1.2. Sample size

Using a formula to calculating correlation coefficient with a value $z\alpha$ of 1.96 with a 95% significance level for two tails, and a $z\beta$ value of 0.84 with a power of 80%, with a minimum expected correlation of 0.3, a sample of 91 patients was obtained.

1.3. Statistical analysis

We used frequencies, measures of central tendency, and dispersion for descriptive statistics, and analyses were developed with parametric and nonparametric tests as appropriate. Correlation tests and linear regression analysis were carried out with the aim of designing a formula that predicts the optimal insertion depth of the CVC into the RIJV in neonates. An algorithm was modeled for the introduction method with the significantly correlated variables for catheter length. The statistical analysis was performed with IBM SPSS version 20 (IBM, Inc., Armonk, NY).

The study was approved by the local ethics committee with registration number PE15-022 and informed consent was obtained from parents of all the patients.

2. Results

We enrolled 98 patients; 7 were eliminated: 6 who were missing data on the distance from the skin to the anterior wall of the vein, and one in whom the postprocedure radiography was not performed. The population studied ($n = 91$) was composed of 50 (54.9%) boys, 40 (43.9%) girls and 1 (1.2%) patient with undetermined sex; 27 (29.7%) patients were full term and 64 (70.3%) preterm, of which 13 were extremely premature. Mean gestational age was 33.4 (25 to 41) weeks, weight 2020 (580 to 3980) g, height 43 (26 to 53) cm and CVC placement was at 9.2 (1 to 28) days of extrauterine life. The anthropometric characteristics compared by weight group are described in Table 1.

2.1. Anatomical characteristics of the RIJV

For the AGA group, the anteroposterior diameter of the RIJV was 3.9 (2.5–6.9) mm while the distance between the skin and the anterior wall of the vein was 5.4 (4.6–7.1) mm. As expected, these values decreased in smaller patients (Table 2). The most frequent anatomical relationship between the RIJV and the carotid artery was lateral in 63.6%, 47.8%, 76.1%, and 64.28% of cases in AGA, LBW, VLBW, and ELBW, respectively.

2.2. Insertion depth of the CVC in the RIJV

A linear regression analysis was carried out to generate a formula that predicts the insertion depth of the CVC in the RIJV in neonates. Variables correlated with the dependent variable (catheter depth) were used and the algorithm was modeled according to the introduction method. It was observed that the highest corrected determination coefficient was obtained for weight ($R^2 = 0.723$) (Table 2, Fig. 2).

With that information, the regression equation results as follows:

$$\boldsymbol{Y = 2.6 + 0.7 \text{ (weight in kg)}}.$$

Where $Y =$ the optimal insertion depth of the CVC in centimeters.

The analysis of multiple variables showed that the combination of other factors (height, head circumference, neck length, etc.) does not significantly contribute to predict the optimal insertion depth of the CVC. The plot of predicted values against residuals suggests that the assumptions of linearity and constant variance are satisfied in our model (Fig. 3).

3. Discussion

The use of CVCs in NICU is a relatively frequent procedure, particularly in preterm infants, since they require a vascular access for the infusion of drugs, hypertonic solutions, or total parenteral nutrition.

The placement of a CVC implies an intrinsic risk to the procedure, which decreases when guided by real-time ultrasound [11,14]. However, there are other issues that must be considered, such as those related to the depth of catheter insertion: arrhythmias, blood vessel perforation, and even cardiac tamponade [15–18].

To prevent complications associated with inadequate placement of the CVC tip, its position should be corroborated immediately after the

Table 1
Anthropometric characteristics.

Variable	Total $n = 91$	AGA $n = 33$	LBW $n = 23$	VLBW $n = 21$	ELBW $n = 14$
GA (weeks)	33.44 (25–41)	38.16 (33.1–41)	33.71 (24.5–40.1)	30.44 (25–39.5)	26.39 (22–30)
Weight (g)	2020.32 (580–3980)	3145.40 (2590–3980)	1879.13 (1500–2480)	1201.19 (1010–1470)	892.28 (580–980)
Height (cm)	43.04 (26–53)	49.58 (48–53)	43.78 (39–50)	38.10 (34–42)	33.86 (26–38)
Neck (cm)	4.52 (3–6)	5.08 (5–6)	4.63 (4–5)	4.14 (4–5)	3.61 (3–5)
MX (cm)	9.24 (6–11)	10.30 (9–11)	9.70 (9–10)	8.52 (8–10)	7.07 (6–8)
MN (cm)	7.38 (5–10)	8.42(7–10)	7.57(7–9)	6.83(6–8)	5.46 (5–7)
HC(cm)	30.36 (18–36)	34.05(31–36)	31.07(28–33)	27.36(24–30)	25.07 (18–34)
RX(cm)	4–06 (2.4–5.7)	4.93(3.9–5.7)	3.91(3–2–5)	3.48(3–1–4.2)	3.14 (2.4–3.8)
RIJVD(mm)	3.1 (1.1–6.9)	3.9 (2.5–6.9)	3.2 (1.8–4.6)	2.8 (1.8–4.4)	2.0 (1.1–2.8)
SWRIJV (mm)	4.7 (2.4–7.1)	5.4 (4.6–7.1)	5.0 (3.2–6.8)	4.2 (2.4–6.5)	3.8 (3.1–4.6)

Values are expressed in mean and range.
GA, gestational age; MX, distance from the mastoid process to the xiphoid process; MN, distance from the mastoid process to the nipple; HC, head circumference; RX, length measured by x-ray from the puncture site to the anterior segment of the carina; RIJVD, anteroposterior right internal jugular vein diameter; SWRIJV, distance from skin to the anterior wall of the right internal jugular vein.

Table 2
Relationship between the optimal insertion depth (cm) and the study variables using linear regression analysis.

	Constant	p-value	β	p-value	R^2
Weight	2.602	< .001	0.000723	< .001	**0.723**
GA	−0.201	0.59	0.127	< .001	0.597
Height	−0.36	0.295	0.103	< .001	0.654
Neck	1.121	0.13	0.651	< .001	0.331
MX	−0.103	0.807	0.451	< .001	0.524
MN	0.321	0.389	0.507	< .001	0.535
HC	−0.575	0.209	0.153	< .001	0.538
RIJVD	2.558	< .001	4.746	< .001	0.310
SWRIJV	2.207	< .001	3.884	< .001	0.274

GA, gestational age; MX, distance from the mastoid process to the xiphoid process; MN, distance from the mastoid process to the nipple; HC, head circumference; RIJVD, anteroposterior right internal jugular vein diameter; SWRIJV, distance from skin to the anterior wall of the right internal jugular vein.

procedure. Traditionally, the imaging method used is chest x-ray; however, in practice several factors may delay the radiography, which means that tip misplacement is not quickly detected, increasing the risk of complications. Furthermore, if the x-ray shows that the tip is deeper than expected, it must be repositioned and will require another x-ray to confirm the position, increasing costs and radiation received by the patient [18–20].

Efforts have been made to create a formula to calculate the optimal insertion depth of umbilical (both venous and arterial) catheters in neonates [21–23]. Besides, previous studies have established that the insertion depth of the CVC is related to age, height, or weight in pediatric population [5,7,24], but there are no data in neonatal patients. According to our study, weight highly correlated with the ideal catheter depth, similar to data reported by Choi et al. [9] in pediatric patients ($R^2 = 0.48$).

Unlike other studies [9,23,24], in our work several variables were evaluated with no statistical correlation found for any other than weight. It is important to note that although the RIJVD and SWRIJV were also statistically significant (P value < .001) to predict optimal insertion depth, regression analysis showed very low R^2 values (0.310 and 0.274, respectively), even lower than previously reported. This indicates that the variance in CVC depth that is predictable from any RIJVD and SWRIJV is very low and therefore, not useful for the proposed formula. After multivariate analysis, it was shown that a combination of other factors (height, head circumference, neck length, etc.) does not

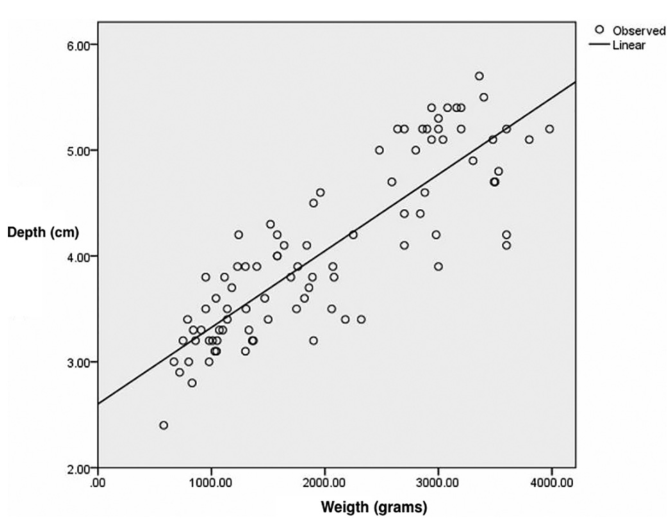

Fig. 2. Optimal insertion length of the catheter in the right internal jugular vein versus weight. Insertion depth (cm) = 2.602 + 0.723 (weight in kg). The slope represents the insertion depth estimated by the equation obtained and the points are the depths observed in the sample for each weight group; it can be seen that these data are adjusted to the optimal line of insertion.

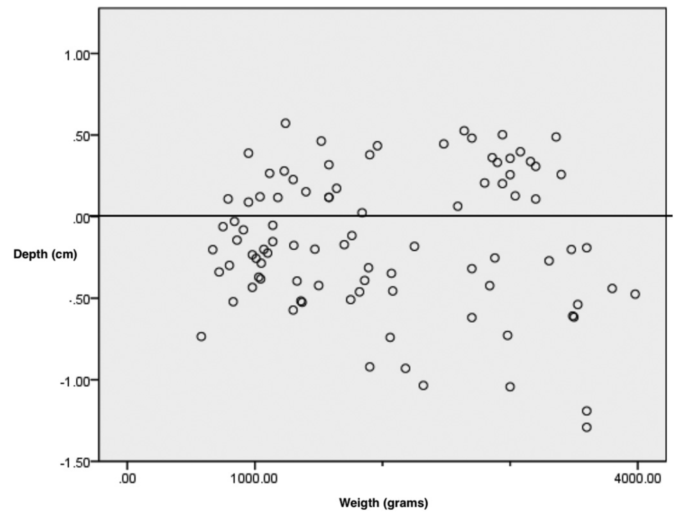

Fig. 3. Residual values versus weight. Each point represents the difference between optimal and estimated (by formula) catheter depth (*Y* axis) across weight ranges (*X* axis). Estimation errors (differences) move around zero for all weight groups.

contribute to predict the ideal depth of the CVC. This makes our model easy to use, practical, and reproducible, since physicians only need to know the patient's weight in order to calculate the depth of the catheter to be inserted.

Regarding the characteristics of the RIJV, it was observed that the most frequent anatomical relationship with the carotid artery was lateral position, similar to that previously reported by our group [12]. There were no significant differences with the measures previously described by the authors.

The placement technique of the CVC, specifically the puncture site, must be considered since in previous studies it has been shown that performing higher or lower punctures could produce differences in the final tip position of the catheter [25,26]. In this study, patient position was carefully selected in each procedure, emphasizing the importance of consistent location of puncture according to anatomical landmarks to achieve a better performance of the proposed model.

Further evaluation of this formula is needed to prospectively validate our current findings in a larger population.

4. Conclusions

This study demonstrates that the weight of the newborn is the most significant predictor of optimal insertion depth of the CVC in the RIJV. The formula that we suggest is a practical and reproducible tool that could reduce the risk of deeper insertion of the catheter and complications related to repositioning the CVC.

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Conflicts of interest

The author declare that they have no conflicts of interest.

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