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Original Article

Comparing two formulas to estimate the correct depth of the neonatal umbilical venous catheter insertion

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Abstract

Aim
The rate of complications among neonates with incorrectly positioned umbilical venous catheters (UVCs) is considerably increased. This prospective study aimed to evaluate whether the use of birth weight (BW) or body surface measurements as a guide for proper depth estimation of the UVC insertion was more accurate.

Patients and methods
A total of 104 neonates were assigned to two groups according to procedure used for proper UVC depth insertion: shoulder–umbilicus length graphs versus BW-based formula. Radiological assessment of correct catheter tip position was determined in both groups.

Results
The overall success rate for UVC insertion was 96% (100/104). However, in 51% (48/94) of the neonates, the UVC was not advanced to the estimated depth. Comparing infants whose UVC was secured at the correct depth and was not in the liver between the weight and measurement method, there was no significant difference in the appropriate site radiologically, but none of catheters not secured at the estimated depth were in appropriate site radiologically in the weight group, whereas some of catheters not secured at the estimated depth were in appropriate site radiologically in the measurement group, with significant difference. However, the weight method shows more sensitivity and accuracy when compared with the measurement group (100 and 75% vs. 50 and 50%, respectively), with the same specificity at 50% each.

Conclusion
A correct depth of insertion was more accurately achieved and showed a higher sensitivity using the BW formulae compared with the body surface measurement method.

Keywords: Insertion depth, neonate, umbilical venous catheter

Introduction

Umbilical venous catheterization (UVC) of newborns was described many years ago [1–3]. The UVCs are frequently used as an important vascular access in neonates [4,5]. Life-threatening complications from UVCs insertion are frequently reported, many of which arise from catheter tip malposition [6]. The UVC passes through the umbilical vein through the ductus venosus and into the inferior vena cava; the optimum position for the catheter tip is at the junction of the inferior vena cava and the right atrium [7,8]. On radiographs, the UVC tip should lie 1 cm above the diaphragm, between the upper border of T9 and the lower border of T10 (T9–T10) [8] (Fig. 1). Review of radiographs showed that the tips were not in the recommended position in half of infants who had UVCs inserted in one study [9]. It is therefore of optimum importance to accurately predict the insertion length and locate the catheter tip site [10–12]. Several formulas and graphs have been proposed to predict the correct position of UVCs [4,13–19]. The most popular method used is the formula of Shukla *et al.* [13], which uses equations based on the birth weight (BW) of the neonate. Another widely

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used method is Dunn's [4] graphs for the shoulder–umbilical length to estimate UVC insertion depth. Several authors have studied both methods in small groups of patients and based their recommendations accordingly. We performed this study to compare the accuracy of both methods in determining the correct position of UVC in both term and preterm neonates on a wider scale.

Patients and methods

The study protocol was approved by the Ethics Committee at the hospital. This randomized blinded prospective study was carried out at the neonatal ICU (NICU) of El Galaa Teaching hospital following the General Organization of Teaching Hospitals and Institutes (GOTHI), Egypt. The study extended between July 2016 and February 2017. The high-flow rate of deliveries approaching 10 000 deliveries/year allows for the high admission rate of high-risk newborns to NICU. Most of these infants require UVC insertion as part of their medical care. All neonatal admissions requiring UVC insertion were eligible for the study.

Exclusion criteria

Neonates with abdominal wall defects, congenital diaphragmatic hernia hydrops fetalis, and major structural heart disease were excluded from the study.

All neonates admitted to NICU had BW measurements in the labor ward following delivery, using an electronic weight scale, and their weights were documented on their admission records accordingly. Randomization of admitted neonates to either group was done using a random number table which was concealed from the treating healthcare providers. Randomization was stratified by BW to neonates less than 1500 or at least 1500 g. The group assignments were labeled on cards placed in closed envelopes and were opened immediately before UVC insertion.

Two formulas for estimation of the UVC tip depth were used.

Measurement formula

Dunn's shoulder to umbilical length graph (Fig. 2) measures the vertical distance from the infants' shoulder tip to the level of the umbilicus (Fig. 3), and this is plotted on the graph to estimate the UVC length of insertion [4].

The other is a BW-based formula proposed by Shukla and Ferrara [13]. The UVC insertion depth (cm)=(BW × 1.5)+5.

Each neonate requiring UVC insertion on admission was allocated to one of either groups: the surface-body measurement group or the BW group.

No consent was needed from the parents or guardians as this is a standard procedure carried out under the blanket consent taken on admission and according to the clinical guidelines of the Neonatology Department. The research consent taken from parents or guardians for enrollment of their neonate in the study was taken individually after the procedure. The UVC was inserted under complete sterile condition according to

Figure 1: Anteroposterior radiograph showing correct catheter tip placement for umbilical venous catheter – between upper border of ninth and lower border of 10th thoracic vertebrae.

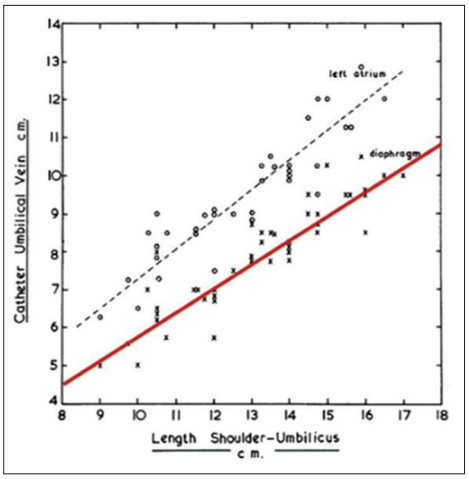

Figure 2: Graphs used in the study relating measurement of the shoulder–umbilicus length to the estimated insertion depth for umbilical venous catheters [4]; the solid (lower red) line indicates the depth that estimates insertion to the diaphragm.

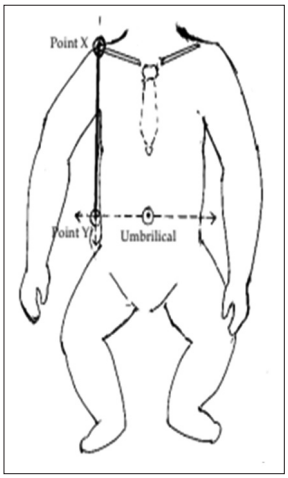

Figure 3: Shoulder–umbilicus length – the distance measured in an inferior vertical direction from the shoulder tip (*x*) to the level of the umbilicus (*y*) – as measured by Dunn [4].

the unit guidelines for infection control measures. A 3.5-Fr double-lumen radio-opaque polyurethane catheter size was used to catheterize neonates less than 1500 g, and a 5-Fr catheter size was used for neonates of at least 1500 grams. If the measurement formula is used, the distance from the shoulder to umbilicus, leveled with the skin of the anterior abdominal wall, is measured and plotted on the graph to calculate the catheter insertion length. If the weight formula is used, the catheter insertion length is calculated from the formula. Neonates were placed supine during the insertion procedure. The catheters were advanced until the marker indicating the estimated insertion depth was at the level of the skin on the abdominal wall, and sutured in place. Blood was aspirated. If the catheter could not be advanced to the estimated depth or blood could not be aspirated, the healthcare provider withdraws it to a position where blood could be aspirated. The level at which the insertion depth is secured was recorded on the assignment card of the neonate. Within 6 hours following UVC insertion, a supine thoracoabdominal radiograph was taken to verify the UVC tip position (Fig. 1). A single radiographer, blinded to either groups, performed the radiography, and similarly, a consultant radiologist masked to the two groups of neonates determined the position of catheter tip. The radiograph was used by clinicians to confirm the catheter tip position and adjust it at their discretion. The radiography was also used to determine the outcome of this study. Correct placement of the UVC was defined as the catheter tip being visible between T10 and T9 on radiography (Fig. 1).

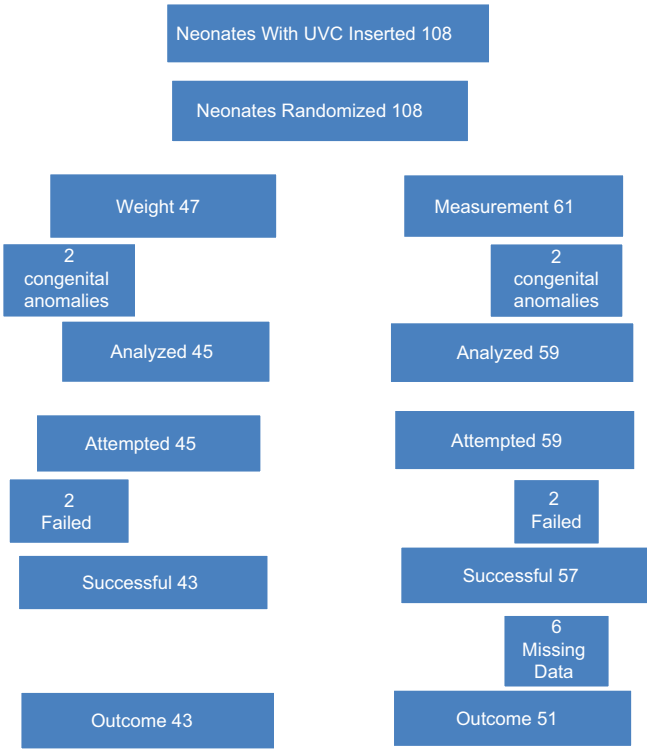

Figure 4: Patient recruitment. UVC, umbilical venous catheter.

Table 1: Patient demographics in weight ($n=43$) and measurement ($n=51$) groups

	Weight ($n=43$)	Measurement ($n=51$)	*P*
Gestational age (weeks)	33.79	32.45	0.066
Body weight (g)	2.1140	1.7902	0.096
Male	24	28	0.060
Day of insertion	2.10	1.89	0.070

Statistical analysis

All results were collected and statistically analyzed using the intention-to-treat principle with PASW, V.20 software (IBM Corp., Armonk, New York, USA). On comparing the outcome with nonparametric tests (Fisher's exact test), *P* values less than 0.05 were considered statistically significant.

Results

A total of 108 neonates underwent umbilical vessel catheterization during this study period. Four neonates were excluded because of congenital anomalies (Fig. 4). The analyzed data for 104 neonates showed that 45 were randomized to the weight and 59 to measurement formula. Infants in both groups were matched for gestational age, BW, and sex at the time of randomization (Table 1).

The UVC insertion was attempted in all 104 infants and was successful in 100 (96%) infants only: 43 in the weight group versus 57 in the measurement group. During analysis, another six infants were excluded from the measurement group for missing data, and only 51 neonates from the measurement group were included in the statistical analysis (Fig. 4). Seven different residents inserted the UVCs, with 6 months to 3 years of experience in the procedure.

All the results are shown in Table 2. Of the UVC successfully inserted, 48/94 (51%) were secured at estimated depth [24/43 (55%) in the weight group vs. 24/51 (47%) in the measurement group)], with no significant difference ($P=0.416$).

The UVC was secured at less than the estimated insertion depth in 28/94 (30%) [15/43 (34%) in the weight group vs. 13/51 (25%) in the measurement group]. The UVC was secured above the estimated insertion depth in 18/94 (19%) [4/43 (9%) in the weight group vs. 14/51 27% in the measurement group].

Neonates who had their UVCs secured at the estimated depth [2/24 (8%) in the weight group and 6/24 (25%) in the measurement group) had the tips of the UVCs at a slightly lower position (<T10) on radiography.

The interpretation of the radiological findings showed that 18 (19%) neonates had their UVCs in a low position, 10 (11%) neonates were in high position, and 38 (40%) neonates had their UVCs in the portal circulation.

Of the UVC successfully inserted, 28/94 (30%) were in the appropriate site radiologically [12/43 (28%) in the weight group vs. 16/51 (31%) in the measurement group], with no significant difference ($P = 0.82$).

Of the UVC that were secured at estimated depth, 28/48 (58%) were in the appropriate site radiologically [12/24 (50%) in the weight group vs. 8/24 (33%) in the measurement group], with no significant difference ($P = 0.308$), and when analyzing infants whose UVC was secured at the correct depth and was not in the liver, 20/34 (59%) were in the appropriate site radiologically [12/18 (67%) in the measurement group vs. 8/16 (50%) in the measurement group], with no significant difference ($P = 0.487$).

None of the neonates with catheters that were not secured at the estimated depth (0 of 19) had their UVC in appropriate site radiologically in the weight group, whereas eight of 27 catheters not secured at the estimated depth were in appropriate site radiologically in the measurement group, with statistically significant difference ($P = 0.014$). If we excluded the catheters that entered the portal circulation, it will be still that none of the neonates with catheters that were not secured at the estimated depth (0 of 6) had their UVC in appropriate site radiologically in the weight group, whereas eight of 16 catheters not secured at the estimated depth were in appropriate site radiologically in the measurement group, with statistically significant difference ($P = 0.049$) (Table 3).

The weight method shows sensitivity of 100%, specificity of 61%, and accuracy of 72%, whereas the shoulder–umbilicus method shows sensitivity of 50%, specificity of 54%, and accuracy 53%, and on excluding the catheters in portal circulation, the weight method shows sensitivity of 100%, specificity of 50% and accuracy of 75%, whereas the

Table 2: Outcomes for umbilical venous catheters

Insertion depth	Weight group ($n=43$)	Radiological findings [n (%)]		Shoulder-umbilical group ($n=51$) [n (%)]	Radiological findings [n (%)]	
Appropriate	24 (56)	In-situ	12 (50)	24 (47)	In-situ	8 (33)
		Above	4 (16)		Above	2 (9)
		Below	2 (9)		Below	6 (25)
		Portal	6 (25)		Portal	8 (33)
Above	4 (9)	In-situ	0 (0)	14 (27)	In-situ	4 (28.6)
		Above	0 (0)		Above	4 (28.6)
		Below	4 (100)		Below	2 (14.2)
		Portal	0 (0)		Portal	4 (28.6)
Below	15 (35)	In-situ	0 (0)	13 (26)	In-situ	4 (31)
		Above	0 (0)		Above	0 (0)
		Below	2 (13)		Below	2 (15)
		Portal	13 (87)		Portal	7 (54)

Table 3: Comparison between weight and shoulder-umbilicus methods

	Weight method		Shoulder-umbilicus method	
	Appropriate radiological Site	Not appropriate radiological Site	Appropriate radiological Site	Not appropriate radiological Site
Including portal UVCs				
Appropriate insertion site	12	12	8	16
Not appropriate insertion site	0	19	8	19
Sensitivity (%)	100		50	
Specificity (%)	61		54	
PPV	0.5		0.33	
NPV	1		0.7	
Accuracy (%)	72		53	
Excluding portal UVCs				
Appropriate insertion site	12	6	8	8
Not the appropriate insertion site	0	6	8	8
Sensitivity (%)	100		50	
Specificity (%)	50		50	
PPV	0.67		0.5	
NPV	1		0.5	
Accuracy (%)	75		50	

NPV, negative predictive value; PPV, positive predictive value; UVC, umbilical venous catheter.

shoulder–umbilicus method shows sensitivity of 50%, specificity of 50%, and accuracy 50% (Table 3).

Discussion

UVCs are crucial in the management of sick neonates both term and preterm to secure an intravenous line for therapeutic administration of parenteral nutrition, blood products, and medication [5]. However, several life-threatening complications are associated with the use of UVCs including thrombus formation, infection, fractured catheter fragments, hepatic necrosis, cardiac arrhythmias and others; often UVC-associated complications result from inappropriate catheter tip position [6]. Accurate placement of UVCs is important to avoid frequent handling of critically ill infants, radiation exposure, and possible catheter-related infections [20–22].

Two most commonly used methods to accurately predict the depth of UVCs are the measurement method of Dunn (based on measurement of the shoulder–umbilicus length) [4] and the method of Shukla (based on BW) [13].

In agreement with a previous cohort study done by Verheij *et al*. [5] we found that comparing neonates whose UVC was secured at the correct depth and was not in the liver between the weight and measurement method, there was no significant difference in the appropriate site radiologically, but none of the catheters not secured at the estimated depth were in appropriate site radiologically in the weight group, whereas some of catheters not secured at the estimated depth were in appropriate site radiologically in the measurement group, with statistically significant difference. However, the weight method shows more sensitivity and accuracy when compared with the measurement group. Verheij *et al*. [5] reported that the overall accuracy of both methods was poor and that they lead to a high rate of overinsertion. In another randomized trial done by Kieran *et al*. [9], it was concluded that using BW to estimate insertion depth did not result in more correctly positioned UVCs. Ades *et al*. [23] reported that almost all catheters placed using the Dunn method and the Shukla method required adjustment after insertion. An unexpected observation in our research is the high rate of UVCs that were in the portal circulation on radiograph. We deduce that the high number of UVCs not inserted to the estimated insertion depth could not be advanced because they entered the portal circulation as they would not pass through the ductus venosus into the inferior vena cava, but it was surprising to find this in 40% (44% weight and 37% measurement) of cases. Techniques have been reported for decreasing the chance of portal placement of the UVC, such as a double-catheter technique [24,25] or external liver mobilization [26].

There is no international consensus on the correct position of UVCs on radiographs. In the studies carried by Dunn [4] and by Shukla [13], they accepted the UVC placement in the right atrium. However, this position is not accepted as optimal and is considered to be too high. In this study, the too high position of UVCs was observed in 11% of cases (9% weight-based formula vs. 12% measurement-based formula). Positioning of the catheter tip above the ninth or below the 10th thoracic vertebra was considered too high or too low, respectively. The reasons for underinsertion were that the healthcare provider could not insert the catheter to the estimated depth and could not aspirate blood from the catheter which was the cause also for overinsertion. We defined the ideal position of the UVC catheter tip when visible at or between the ninth or 10th thoracic vertebra [15]. On the basis of radiological findings, some authors advocate that the tip should be positioned at or just above the diaphragm, whereas others advise that the tip should be between the eighth and ninth thoracic vertebra or between the eighth to 10th vertebra [11,27–29]. In contrary, several other authors recommend that the tip should lie at least 0.5 cm outside the cardiac line in small neonates or 1.0 cm in larger babies [30]. These differences are mainly owing to the difficulty to relate anatomical structures to the projection of vertebral bodies on thoracoabdominal radiographs because of the variability of these structures in relation to bony landmarks. Greenberg *et al*. [31] correlated the position shown by ultrasonography to the nearest vertebral body on radiography. UVCs positioned at the eighth and ninth thoracic vertebra on radiography were positioned at the inferior vena cava (IVC)/right atrial junction in 90% of cases. UVCs positioned below the 10th thoracic vertebra were all in the liver proximal to the ductus venosus [31]. When ultrasound assessment is not available, the authors suggested that the correct position for the catheter tip on chest radiography should be on the eighth and ninth thoracic vertebrae. Ades *et al*. [23] showed poor correlation between the thoracic level on radiography and the position of the tip on ultrasonography. They found that the catheter tips at the IVC/right atrial junction and IVC were located at the thoracic vertebral bodies 6–11. Ultrasonography allows to determine directly the correct position of the catheter, before even it is secured at the recommended position. Limitations to routine use of ultrasonography is that it requires qualified practitioners to be able to perform round the hour. Accordingly, most centers (including ours) are forced to use thoracoabdominal radiography to assess the catheter tip position [11,32–37].

A strength of our research is that the radiologist determining the outcome was unaware of group assignment and the appropriateness of the estimated depth. Radiography was used to determine the outcome of our study, as this is the method most commonly used in clinical practice, either in our unit or worldwide; moreover, it is the method used in most of previous studies and most often recommended in guidelines [5,7,15,18].

Limitations

Despite that the number of neonates included in this study was more than that included in other several studies, a larger number would have given more confirmative results. The healthcare providers performing the UVC insertion were not blinded to the neonates' group assignment. It was found that

the marks on the catheters used are often inaccurate [38]. The differences between the indicated and actual distance from the tip are small. We think that randomization should have balanced any effect of inaccuracies in markings between the groups as the model of catheter was the same in all enrolled neonates. Apparently many clinicians do not know the right method to measure the shoulder–umbilicus length. A survey of 101 pediatricians, including 45 consultants, showed that only 14/101 (14%) used the correct measurement described by Dunn [39]. In our unit, it appears that several healthcare providers need to be trained to use the correct method of estimating shoulder–umbilicus length, being poorly aware of the technique.

Conclusion

This study showed that using BW-based formula in assessing length of UVC insertion in neonates had higher sensitivity and accuracy compared with the measurement-based formula. Inability to advance the UVCs to the estimated insertion depth and the presence of the catheter tip in the portal venous system on radiography were often found. There was no significant difference in the appropriate site radiologically but none of the catheters not secured at the estimated depth were in appropriate site radiologically in the weight-based group whereas some of catheters not secured at the estimated depth were in appropriate site radiologically in the measurement-based group, which was statistically significant. Ultrasonography should become one of the routine skills of all healthcare providers in neonatal wards involved in the placement of umbilical catheters. We strongly recommend the use of bedside real-time ultrasonography as the gold standard in verifying the position of umbilical catheters, as previously suggested by several authors [10,23,29,31].

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Conflicts of interest

There are no conflicts of interest.

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