Accuracy of Yoon's Formula for Predicting Central Venous Catheter Depth in Indonesian Pediatric CHD Patients: A Cross Sectional Study

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ABSTRACT

Background: A central venous catheter is a routinely inserted tool by anesthesiologists in open-heart surgery. However, incorrect central venous catheter placement depth may lead to complications or suboptimal usage. Yoon's research in 2006 was done in paediatrics with congenital heart disease in Asia and developed a prediction formula for the depth of central venous catheter. This study aims to prove if Yoon's formula can be applied to pediatric patients with congenital heart disease in Indonesia.

Methods: This analytic observational study, with a cross-sectional design, involved 38 patients undergoing open-heart surgery in RSCM. Yoon's formula determines the depth of central venous catheter placement. Transesophageal echocardiography assessed the position of the tip of the central venous catheter from the cavoatrial junction to confirm the depth's accuracy.

Results: Yoon's formula can predict the optimal depth of the central vein catheter 63.16% of the time. There was no complication before central venous catheter placement. This study is limited to right internal jugular vein placements, reducing its generalizability to other insertion sites. Further research with a larger sample and varied approaches is needed to enhance accuracy and develop a more suitable formula.

Conclusion: Yoon's formula is inappropriate for predicting the depth of central vein catheters in pediatric patients with congenital heart disease in Indonesia, but it can still be applied clinically.

Keywords: Central venous catheter; congenital heart disease; pediatrics; transesophageal echocardiography; yoon's formula

Ketepatan Rumus Yoon dalam Memprediksi Kedalaman Kateter Vena Sentral pada Pasien Anak dengan PJB di Indonesia: Studi Cross-Sectional

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ABSTRAK

Latar Belakang: *Kateter vena sentral merupakan alat yang rutin dipasang oleh anestesiologis pada pembedahan jantung terbuka. Namun, kedalaman pemasangan kateter vena sentral yang tidak tepat dapat menyebabkan komplikasi atau penggunaannya suboptimal. Penelitian oleh Yoon dilakukan pada anak dengan penyakit jantung bawaan di Asia dan menghasilkan rumus prediksi kedalaman kateter vena sentral. Penelitian ini bertujuan untuk membuktikan apakah rumus Yoon dapat digunakan pada populasi anak dengan PJB di Indonesia.*

Metode: *Penelitian ini merupakan uji observasional analitik dengan rancangan penelitian potong lintang dan melibatkan 38 pasien yang menjalani pembedahan jantung terbuka di RSCM. Kedalaman kateter vena sentral ditentukan menggunakan rumus Yoon. Konfirmasi ketepatan kedalaman kateter vena sentral dilakukan dengan menggunakan transesophageal echocardiography untuk melihat posisi ujung kateter terhadap pertemuan vena kava superior dan atrium kanan.*

Hasil: *Rumus Yoon dapat secara tepat memprediksi kedalaman kateter vena sentral pada 63,16% pemasangan. Tidak ada komplikasi dari pemasangan kateter vena sentral yang terlalu dalam. Studi ini terbatas pada pemasangan kateter vena sentral melalui vena jugularis interna kanan, sehingga hasilnya kurang dapat digeneralisasikan ke lokasi pemasangan lainnya. Penelitian lebih lanjut dengan sampel yang lebih besar dan metode pemasangan yang beragam diperlukan untuk meningkatkan akurasi dan mengembangkan formula yang lebih sesuai.*

Simpulan: *Rumus Yoon kurang tepat digunakan sebagai pedoman dalam memprediksi kedalaman kateter vena sentral pada pasien anak dengan PJB di Indonesia, namun masih dapat diaplikasikan secara klinis.*

Kata kunci: *Kateter vena sentral; pediatric; penyakit jantung bawaan; rumus yoon; transesophageal echocardiography*

INTRODUCTION

Anesthesiologists often perform central venous catheter placement to monitor intraoperative hemodynamics and critical patients in the ICU. Central venous catheters also function as access for administering fluids and medications, especially parenteral nutrition, irritant fluids, and cardiovascular drugs. Central venous catheters can also facilitate dialysis or plasmapheresis procedures and act as an insertion path for additional devices for more complex procedures.[1,2] Installation of central venous catheters in children, especially neonates and infants, is quite challenging because it is more technically difficult. The small anatomical size also often causes inaccuracy in the position of the central venous catheter tip. A position that is not deep enough can cause inaccuracy in hemodynamic monitoring, suboptimal drug delivery, and the risk of thrombosis.[3,4] A central venous catheter placed too deep can cause arrhythmias, cardiac perforation, and cardiac tamponade. Previous studies on 51 central venous catheter placements found that 41% experienced atrial arrhythmias and 25% experienced ventricular ectopy.[5] The incidence of cardiac tamponade in children due to central venous catheter placement ranges from 1-3%, and the mortality rate is 30-50%. Although this complication is rare, its impact is large.[6] In clinical practice, excessive catheter depth often causes the surgeon to cut the tip of the catheter. This can potentially cause other complications, such as catheter tip pieces that are lost or enter the circulation and become emboli.[7]

The position of the central venous catheter tip can be confirmed by various methods such as transthoracic and intracardiac ECG, transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), fluoroscopy, CT scan, chest X-ray (CXR), or direct confirmation by the surgeon.[3,8] However, some modalities are not always available, and some require operator time or expertise for the examination. Several previous studies have produced a formula for measuring the depth of the central venous catheter to facilitate predicting its depth so that it is in the right position. Although this formula has been formulated, problems are often encountered in children with CHD because the anatomical size does not always match their age, so the prediction methods for anesthesia equipment can be inaccurate. One of the newest formulas for predicting central venous catheter depth, developed in Asia, is the Yoon (2006) formula, which uses length/height variables.[3] Other existing formulas were derived from earlier research on non-Asian populations. Predicting the depth of a central venous catheter using a formula aids in the quick, easy, inexpensive, and precise placement of the catheter, eliminating the need to wait for confirmation from other examinations.[9,10]

This research aims to determine whether the Yoon formula can be applied to the population of children with congenital heart disease (CHD) in Indonesia. The research subjects are limited to children with CHD who are scheduled to undergo cardiac correction surgery. This study is significant because using an accurate formula to predict the depth of a central venous catheter can help prevent complications arising from incorrect catheter tip placement.

METHOD

This is an analytical observational study with a cross-sectional design aimed at evaluating the accuracy of the Yoon formula in predicting central venous catheter depth in pediatric patients with congenital heart disease (CHD) in Indonesia. The study was conducted at the Integrated Heart Services (PJT) unit at RSUPN Dr. Cipto Mangunkusumo (RSCM) Jakarta from April to May 2023, with a total sample of 38 subjects. The required sample size for this study was determined using a two-proportion difference test for independent groups. The estimated sample size is as follows:

$$n_1 = n_2 = \left\{ \frac{(Z_\alpha \sqrt{2P(1-P)} + Z_\beta \sqrt{P_1(1-P_1)+P_2(1-P_2)}}{(P_1 - P_2)} \right\}^2$$

$$n_1 = n_2 = \left\{ \frac{(1{,}96\sqrt{2x0{,}72x0{,}28} + 1{,}28\sqrt{(0{,}96x0{,}04)+(0{,}48x0{,}52)}}{0{,}48} \right\}^2$$

n1 = sample size in the group with correct central venous catheter depth
n2 = sample size in the group with incorrect central venous catheter depth
a = significance level (set at 5%)
Za = for a of 5%, from the two-tailed table, Za = 1.966
Zb = for b of 10%, from the two-tailed table, Zb = 1.28
P1 = proportion of correct central venous catheter depth (0.96)
P2 = proportion of incorrect central venous catheter depth (0.48)

Based on the sample size calculation, 17 subjects were required. Considering an estimated 10% dropout rate, the adjusted sample size is 18.7, rounded to 19 subjects per group. Thus, the total sample size for both groups is 38 subjects.
Inclusion criteria were children with CHD aged 1-200 months and with a height of 40-140 cm, undergoing open-heart surgery, and requiring the placement of a central venous catheter in the right internal jugular vein. Exclusion criteria included a history of previous cardiac surgery, anatomical neck abnormalities, or refusal to participate. The parents of patients who meet the eligibility criteria will receive clear research information, and they will be asked to sign a written informed consent form as a requirement for voluntary participation in the study. The ethics of this study were approved by the ethics committee of Dr. Cipto Mangunkusumo Hospital, with ethics code number KET-271/UN2.F1/ETIK/PPM.00.02/2023. The research protocol includes anamnesis, physical examination, and calculation of the predicted depth of the central venous catheter using the Yoon formula before installation. The insertion location and catheter size are adjusted according to body weight. Depth confirmation is performed using the TEE bicaval view. Statistical analysis is conducted using SPSS version 22, employing the Mann-Whitney test to evaluate the impact of age, weight, and height on depth accuracy and Spearman's Rho test for correlation. The results are presented in a table illustrating the relationship between these factors and the accuracy of central venous catheter depth.

RESULT

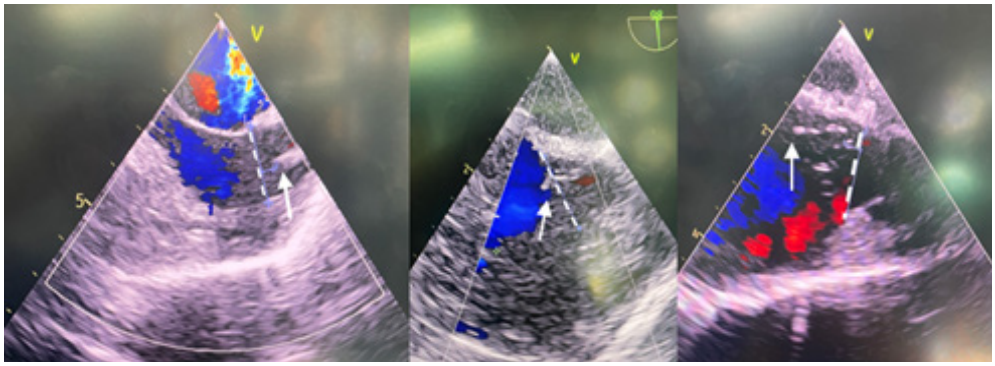
A total of 39 cyanotic and acyanotic CHD patients met the study criteria; however, one child was excluded due to a history of previous heart surgery, resulting in 38 subjects being included in the analysis. The characteristics of the subjects in this study are presented in Table 1.

Table 1. Subject's characteristics

Demographic	Median (Min – Max)	N (%)
Gender		
Male		21 (55,26%)
Female		17 (44,74%)
Age (year)	1,79 (0,083 - 11,90)	
Weight (kg)	9,1 (3,60 - 31,50)	
Length/Height (cm)	81,5 (54 - 139)	
CHD Type		
Cyanotic		23 (60,53%)
Acyanotic		15 (39,47%)

Central Venous Catheter Depth Measurement Using Yoon's Formula

Based on the operational definition, the depth of a central venous catheter is considered "appropriate" if the tip's position is between 0 and 0.5 cm above the junction of the superior vena cava and right atrium. The position of the central venous catheter tip can be seen using transesophageal echocardiography, as shown in Figure 1 below.



(A)Not deep enough (B) Appropriate (C) Too deep
The line where the superior vena cava meets the right atrium
Position of the central venous catheter tip

Figure 1. CVC tip position from transesophageal echocardiography

In this study, not all central venous catheter depths fell into the "appropriate" category. While the depth was correct in some subjects, it was either too deep or not deep enough in others. Using the Yoon formula, 24 subjects had the correct central venous catheter depth, while 14 had incorrect depths. Three subjects had the catheter tip positioned too deeply, and 11 subjects had the tip positioned too shallowly. The measurement results and percentages for the 38 subjects are presented in Table 2.

Table 2. Central venous catheter depth measurement results

Central Venous Catheter Tip Position	Minimum - maximum distance range (cm)	Total	Percentage
Appropriate	-0,50 – 0,00	24	63,16%
Too deep	-0,60	3	7,89%
Not deep enough	+0,10 – +0,40	11	28,95%

Table 2 shows that the correct position of the central venous catheter tip is within the range of -0.50 to 0.00 cm from the junction of the superior vena cava and right atrium. The three measurements with the catheter positioned too shallowly were within -0.60 cm of this junction. Meanwhile, measurements indicating an excessively deep catheter position were at a maximum of +0.40 cm from the junction of the superior vena cava and right atrium.

The median distance for measuring the tip of the central venous catheter using Yoon's Formula in the inappropriate group (n=14, 36.84%) was shorter (median: 7.13 cm, range: 6.18-10.80 cm) compared to the appropriate group (n=24, 63.16%), which had a median distance of 7.44 cm (range: 5.48-11.43 cm). Despite this observed difference in medians, statistical analysis using the Mann-Whitney test indicated that the difference was not significant ($p = 0.865$), suggesting that the variation in catheter depth between the inappropriate and appropriate groups may be due to random variation rather than a systematic difference in the application of Yoon's formula.

Table 3. Yoon's formula measurement compared to the actual distance of the central venous catheter based on the precise location of the central venous catheter tip

	Mean Distance to the Meeting of the Superior Vena Cava and Right Atrium (cm)	Median	Min-Max
Too Deep	+0,23	+0,20	+0,10 – (+0,40)
Not Deep Enough	-0,60	-0,60	7,89%
Appropriate	-0,22	-0,25	28,95%

Based on Table 3 above, the results showed that in the group of subjects with the appropriate location of the central venous catheter tip using Yoon's formula, the tip was, on average, located 0.23 cm above the junction of the superior vena cava and right atrium. In the group where the catheter tip was positioned too deeply, the average distance was 0.22 cm below this junction. Conversely, in the group where the catheter tip was not deep enough, the average distance was 0.6 cm above the junction of the superior vena cava and right atrium.

Distribution of Central Venous Catheter Depths Based on Age, Body Weight, and Height

The analysis of central venous catheter depths, based on age, body weight, and body length/height, indicates a consistent positive linear relationship with the actual catheter distance required. Each scatter plot confirms that as these anthropometric parameters increase, the necessary catheter depth also increases. Specifically, age, body weight, and body length/height are shown to be significant predictors of the optimal catheter placement distance, demonstrating strong positive correlations with the required depth. This underscores the importance of considering these factors when determining central venous catheter placement. The results show that the age, weight, and height variables are each significantly related to the actual distance of the central venous catheter, as shown in Table 4.

Table 4. Correlation between age, body weight, and body length/height on actual central venous catheter distance

Parameter	Correlation	Age	Body Weight	Body Length/ Height
Actual Distance	r_s	0,949	0,948	0,987
	p	<0,001	<0,001	<0,001
	n	38	38	38

Spearman's Rho Test

DISCUSSION

Accuracy of Yoon's Formula

The results of this study indicate that the Yoon formula can accurately predict the location of the central venous catheter tip at a distance between 0 and 0.5 cm above the junction of the superior vena cava and right atrium in 63.16% of placements. This accuracy is notably different from the 97.5% accuracy reported by Yoon in 2006.[6] The discrepancy in the three subjects was the central venous catheter being positioned too shallowly. In this group, the mean position of the catheter was 0.60 cm above the junction of the superior vena cava and right atrium. This positional inaccuracy deviates by 0.1 cm from the specified central venous catheter placement accuracy limit.

The most common inaccuracy in central venous catheter depth in this study was the tip being positioned too deeply. Out of the 14 subjects with incorrect placements, 11 fell into this category. The average position of an overly deep

central venous catheter was 0.23 cm below the junction of the superior vena cava and right atrium. The results indicated that most inaccuracies were due to the catheter being too deep. Only three subjects had catheters that were "not deep enough," deviating by just 0.1 cm from the "correct" limit, whereas the 11 subjects with catheters placed too deeply deviated by 0.23 cm. This suggests that some subjects in this study were shorter than those in Yoon's research.

The differences in the results of this study compared to Yoon's research may be attributed to several factors—first, the wide height range of the subjects, from 54 cm to 139 cm. However, Yoon's formula is designed to be accurate for children with a height of 40-140 cm, suggesting that height range is not the cause of the formula's lack of precision in this study. Another possible factor is the racial differences among the subjects. While Yoon's research did not specify the racial characteristics of the subjects, it was conducted at Seoul National University Hospital, implying that the subjects were likely of the Mongoloid race (Asiatic Mongoloid). In contrast, the subjects in this study, referred to as "Indonesian children," are not a homogeneous population. They belong to various ethnicities, including the Malay and Mongoloid races. The height of individuals can vary significantly across different geographic locations and racial groups, and different racial groups can also respond differently to the same environmental factors.[11] Therefore, racial differences can influence several anthropometric parameters.

According to the NCD Risk Factor Collaboration, there are notable height differences between South Korean and Indonesian residents. In 2019, the average height of boys in the 5-year age group was 113 cm in South Korea, compared to 107 cm in Indonesia. Similarly, the average height of girls in the 5-year age group was equivalent to that of boys in each respective country. For the 11-year age group, the average height for boys in South Korea was 149 cm, while it was 137 cm in Indonesia. In the same age group, the average height for girls in South Korea was 149 cm, compared to 139 cm in Indonesia.[12] This indicates that the height of the Indonesian children in this study is relatively shorter than that of Korean children. Consequently, the measurement results showed that the central venous catheter was positioned too deeply in 11 subjects (28.95%). However, this conclusion is assumptive, as the study did not record the ethnicity or race of the research subjects in detail alongside the measurement results.

Aside from racial factors, the primary cause of height differences between the two countries may also be attributed to differences in nutritional standards. Malnutrition remains a prevalent cause of growth failure worldwide. Health status also significantly influences physical development. Diseases resulting from a compromised immune system and poor nutrition can adversely affect growth.[11] However, this analysis could not be performed in the current study due to the lack of data on each subject's nutritional status.

Relationship between Age, Body Weight and Body Length/Height with Central Venous Catheter Depth

The Peres, Andropoulos, and Yoon formulas all use body length/height variables to predict the actual distance of the central venous catheter. It was also recommended central venous catheter depth based on body weight variables.[9] The results of this study indicate that age, weight, and length/height of children with CHD in Indonesia each significantly influence the actual distance of the central venous catheter. An increase in age, weight, and body length/height corresponds to the rise in the actual distance of the central venous catheter.[13] However, the research data did not allow for the creation of a linear regression that would yield a formula superior to Yoon's. Larger-scale research is needed to develop a more accurate formula for central venous catheter depth in pediatric CHD patients in Indonesia.

Complication

The placements of all central venous catheters in this study used the Yoon formula to predict the catheter's depth. Evaluation using TEE revealed 11 instances where the catheter tip was positioned beyond the confluence of the superior vena cava and right atrium, with the maximum distance being +0.40 cm. However, no complications were reported due to central venous catheter placement in the study samples.

Applicability of the Yoon Formula

The accuracy of Yoon's formula in this study was 63.16% for central venous catheter placements. Nonetheless, the central venous catheter tips that were not deep enough differed by only 0.1 cm from the correct position. Conversely, the 11 catheter placements that were too deep had tips ranging from +0.10 cm to +0.40 cm, with an average distance of +0.23 cm from the correct position. Only one placement reached +0.40 cm. This inaccuracy could be influenced by the variability of measurements in dynamic heart chambers. Importantly, no complications arose from any of the deeply placed catheters. Thus, although Yoon's formula may be less accurate statistically, it remains clinically applicable to pediatric CHD patients in Indonesia.

Research Limitations

This study exclusively evaluates the formula's accuracy for predicting the depth of central venous catheters placed in the right jugular vein. Consequently, the results cannot be generalized to catheter placements from other locations, such as the left jugular vein, subclavian vein, or axillary vein. Research by Andrews (2000) on adult patients demonstrated variations in the depth of central venous catheter placement depending on the location: 16 cm in the right internal jugular vein, 19.1 cm in the left internal jugular vein, 18.4 cm in the right subclavian vein, and 21.2 cm in the left subclavian vein.14 In this study, placing a central venous catheter in the jugular vein was standardized using the central approach, suggesting that the results may not be applicable when using the anterior or posterior approach. Different approaches to installing a central venous catheter can alter the catheter insertion point in the skin, thus affecting the distance from the skin to the junction of the superior vena cava and right atrium.

CONCLUSION

Yoon's formula is inappropriate for predicting central venous catheter depth in pediatric patients with CHD in Indonesia. However, it can be applied clinically in these patients. The factors of age, weight, and body length/height were independently positively correlated with the actual distance of the central venous catheter. Further research is required to validate the accuracy of Yoon's formula by recording more comprehensive subject data, including race and nutritional status. Additionally, further studies should investigate the accuracy of the Yoon formula when installing central venous catheters using various approach methods. Large-scale research is needed to develop a central venous catheter depth formula suitable for pediatric CHD patients in Indonesia.

CONFLICT OF INTEREST

The author declares that they have no competing interests.

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