

The fourth thoracic vertebra as a radiographic landmark for the depth of right internal jugular vein catheterisation in infants: A retrospective study

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Abstract

Background The carina is considered a reliable marker for the depth of right internal jugular vein catheterisation in infants. However, the carina is not always visible on chest radiographs, whereas vertebral bodies usually are. We performed a retrospective analysis of routine post-procedural chest radiographs of infants who had undergone congenital heart surgery and required central venous catheterisation. We evaluated the possibility of using vertebral bodies as radiographic landmarks for the identification of the depth of right internal jugular vein catheterisation.

Methods In total, 108 infants (aged 1–12 months) who underwent congenital heart surgery from the 1st of January, 2019, to the 30th of June, 2019, were included. We analysed the post-operative chest radiographs of those who underwent right internal jugular vein catheterisation and assessed the visibility of the carina and vertebral bodies, as well as their positional relationship.

Results In total, 95 children were enrolled; in 61 (64%) cases, the carina was visible on the chest radiograph, whereas in 34 (36%) cases, it was not visible. In all 95 (100%) cases, the vertebral bodies were clearly visible. There was a significant difference between the rate of visibility of the carina and vertebral bodies ($P=0.01$, $P<0.05$). The carina was located at the third thoracic vertebra in one case (2%) and at the fourth thoracic vertebra in 60 cases (98%). There was a significant difference in the position of the carina ($P=0.01$, $P<0.05$).

Conclusions Most fourth thoracic vertebrae were at the same level as the carina on chest radiographs. The fourth thoracic vertebra, therefore, has potential as a radiographic landmark for the depth of right internal jugular vein catheterisation in infants when the position of the carina is not visible on the chest radiograph.

Background

Central venous catheterisation is an important cardiac surgery technique. The right internal jugular vein is the most used central venous catheter (CVC) placement site in infants; due to their relatively small size and short superior vena cava (SVC) length, determining catheterisation depth requires a high level of precision to avoid arrhythmia, heart injury, and surgical interference.^{1,2} When such catheterisation is too shallow, it leads to inaccurate measurement of central venous pressure and poor fluid and blood transfusion; the catheter may even be pulled out. At present, there are various methods for measuring the depth of the right internal jugular vein catheter in infants, such as transthoracic echocardiography³, intraluminal electrocardiography, transoesophageal echocardiography^{4,5}, and surface anatomy.⁶ Derived formulas for calculating the depth of catheter insertion are available based on height and weight measurements.⁷ However, each method relies on the carina as a landmark for CVC placement in children. An anatomical measurement of infant cadavers revealed that the carina is located 22 mm above the junction of the superior vena cava and right atrium,⁹ while clinical studies have revealed that the optimal depth of CVC tip placement is at the level of the carina.^{8–10} The position of the carina is usually

determined via chest radiography; however, we have observed that the carina is not always visible on chest radiographs in infants, possibly due to the condition of the patients and radiation parameters. Therefore, in some cases, it is difficult to rely on the position of the carina to determine the right internal jugular vein catheter depth in infants. However, vertebral bodies are very clear on chest radiographs; in adult anatomy, the carina is typically located at the level of the fifth thoracic vertebra.¹¹ We are not aware of a positional relationship between infant carina and thoracic vertebra. We hypothesised that a vertebral body may serve as a radiographic landmark for the depth of right internal jugular vein catheterisation when the position of the carina is not visible on a chest radiograph.

Methods

This study was approved by the Ethics Committee of Beijing Children's Hospital, China (No. 2020-K-015) on the 20th of February, 2020. We retrospectively analysed 108 children aged between 1 and 12 months who underwent cardiac surgery at Beijing Children's Hospital, affiliated with Capital Medical University, from the 1st of January, 2019, to the 30th of June, 2019. Informed patient consent was waived due to the retrospective nature of the study.

In this retrospective study, we aimed to analyse the relationship between the carina and thoracic vertebra in infants to determine the presence of a vertebral body, at the same level as the carina, that could be used as a radiographic landmark to guide the depth of right internal jugular vein catheterisation in infants. In total, 98 cases of right internal jugular vein catheterisation were confirmed via post-operative chest radiography. The first post-procedural chest radiograph of each child was analysed using the Carestream Picture Archive and Communication System (PACS; Carestream Health Inc., Rochester, NY, USA). The following parameters were analysed: 1) the visibility of the carina and vertebral bodies on the chest radiograph, where the position of the carina was determined as the point of division of the trachea into the left and right bronchi; 2) the positional relationship between the carina and the vertebral bodies; and 3) the position of the CVC tip on the chest radiograph.

All measurements were performed by experienced radiologists using the hospital's PACS software; all catheters were inserted under general anaesthesia. Catheterisation was performed by an anaesthesiologist, experienced in right internal jugular vein catheterisation, without measuring instruments or auxiliary devices. Due to the retrospective nature of the study, details regarding catheter placement were not clear.

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics for Mac version 21 (IBM Corp., Armonk, NY, USA). Normally distributed data are expressed as the mean \pm standard deviation, and non-normally distributed data as the median and interquartile range (IQR). Statistical significance was determined as $P < 0.05$ using the Chi-squared test.

Results

We reviewed the radiographs of 108 consecutive infants who underwent cardiac surgery; chest radiographs revealed that 98 of these patients underwent right internal jugular vein catheterisation. Due to the overlap of the CVC and other cardiac leads, the data of three infants could not be assessed; therefore, we enrolled and assessed 95 infants, as indicated in Fig. 1. The infants' sex, age, weight, and medical diagnosis are summarised in Table 1.

Table 1
Infant demographic characteristics

Variable	Value
Age, median (IQR), months	4 (3–5)
Weight, mean \pm standard deviation, kg	5.6 \pm 1.4
Sex, male/female, No. (%)	56/39 (59/41)
Diagnosis, No. (%)	66 (70)
Ventricular septal defect	2 (2)
Atrial septal defect	4 (4)
Tetralogy of Fallot	4 (4)
Total anomalous pulmonary venous connection	5 (5)
Patent ductus arteriosus	5 (5)
Aortic coarctation	9 (10)
Others	
Abbreviations: IQR, interquartile range	

The carina was only visible on the chest radiograph of 61 cases (64%) (not the other 34 cases (36%)), while the vertebrae were clearly visible in all cases (100%); there was a statistically significant difference between the rate of visibility of the carina and vertebral bodies ($P = 0.01$, $P < 0.05$; Fig. 2). Analysis of the 61 cases where both the carina and vertebral bodies were visible revealed that the carina was located at the third thoracic vertebra in one case (2%), and the fourth thoracic vertebra in 60 cases (98%); this difference in carina location was statistically significant ($P = 0.01$, $P < 0.05$; Fig. 3).

The average distance between the tip of CVC and the fourth thoracic vertebra was 11 ± 8 mm in 95 children. The measurement of the vertical distance between the CVC tip and the fourth thoracic vertebra is demonstrated in Fig. 4, while the position of the catheter tip relative to the level of the fourth thoracic vertebra in the 95 patients is summarised in Table 2. In one case, a CVC tip was placed 40 mm below the level of the fourth thoracic vertebra.

Table 2
Positional relationship between the CVC tip and the fourth thoracic vertebra

Position of the CVC tip relative to the fourth thoracic vertebra	% (No. cases)
Above	3%
At the same level	20%(19)
Below (within 22 mm)	70% (66)
Below (more than 22 mm)	7% (7)
Abbreviations: CVC, central venous catheter	

Discussion

In this study, we retrospectively analysed the post-operative chest radiographs of infants who underwent cardiac surgery and assessed the possibility of using a vertebral body as a radiographic landmark for the identification of the depth of right internal jugular vein catheterisation. CVC insertion, including internal jugular vein catheterisation, femoral vein catheterisation, and subclavian catheterisation, is a very important perioperative technique. Currently, the most widely utilised form is right internal jugular vein catheterisation.¹² The optimal timing of surgical treatment for children with certain congenital heart diseases is during infancy. Infants have a relatively large head and short neck; therefore, it is difficult to insert and place the right internal jugular vein catheter, especially in terms of the appropriate depth. There have been reports that improper CVC placement can cause serious complications in infants.¹³⁻¹⁵

According to current literature, the carina can be used as a reliable reference index for the depth of right internal jugular vein puncture. In this study, we retrospectively analysed post-operative chest radiographs of infants and observed that the carina was not clearly visible in a substantial proportion (36%) of chest radiographs; however, the vertebral bodies were clear in 100% of cases. Moreover, we discovered that the fourth thoracic vertebra was at the same level as the carina in most cases (98%), contrary to what is observed in adults¹¹; this discrepancy may be due to differences in the physical development stages of infants and adults. Our results suggest that the fourth thoracic vertebra can also be used as a radiographic marker for optimal CVC positioning, which may reduce complications.

Previous studies on the depth of right internal jugular vein catheterisation in infants, e.g. that of Lopéz Álvarez et al.,¹⁶ have relied on special equipment for guidance, such as those used during transoesophageal echocardiography and ultrasonography; these are expensive, difficult to operate, and not suitable for most hospitals. Other researchers, such as Uchida et al.,¹⁷ have relied on chest radiography to locate the carina for the optimal placement depth of the CVC. As discussed above, this is not possible in all cases; we could only distinguish the general anatomy of the trachea, as well as that of the left and right main bronchi; only the approximate position of the carina was determined.

The distance from the fourth thoracic vertebra to the CVC tip in our study was 11 ± 8 mm; in 77% of cases, the tip was below the fourth thoracic vertebra. In a previous study, it was revealed that the junction of the superior vena cava and the right atrium may be 22 mm below the carina in infants.⁹ We therefore speculated that the CVC may be too deep when placed more than 22 mm below the fourth thoracic vertebra, as this may cause the CVC to enter the right atrium. In this study, there were seven cases where the CVC tip was located more than 22 mm below the fourth thoracic vertebra; in one case, the distance from the CVC tip to fourth thoracic vertebra was 40 mm. Theoretically, the CVC may enter the right atrium when placed at such a depth; however, such a complication was not recorded by the surgeons. In 66 cases, the catheter tip was located no more than 22 mm below the fourth thoracic vertebra; we speculate that the CVC tip is located in the lower segment of the superior vena cava when placed at this depth, which is reported as the most suitable depth.^{18,19} However, it has been reported²⁰ that head position may have an effect on the internal jugular vein size and, thus, the catheter tip position. If placed near the fourth thoracic vertebra or carina, this effect is likely minimal; however, if the CVC is placed closer to the right atrium, a change in head position may cause the catheter to enter the right atrium, interfering with the operation and risking complications such as cardiac perforation and tamponade. Since we did not require the same head position during data collection, a closer proximity of the catheter tip to the right atrium increases the risk of complications. Based on the above analysis, the CVC should be withdrawn approximately 10 mm, on average, to the level of the fourth thoracic vertebra; this seems to be a reliable indication of a safe CVC depth for the children analysed in this study. According to our observations, the CVC tip was located above the fourth thoracic vertebra in a safe position in three cases. However, a position that is too high would lead to inaccurate determination of the central venous pressure, increasing the risk of the catheter being pulled out.

This was a retrospective study, which resulted in certain limitations. First, post-operative chest radiography was not performed using standardised radiographic parameters for observing the position of the carina; therefore, not all carina were visible. However, regardless of the radiation parameters, vertebral bodies were clearly visible. Second, during chest radiography, the infants' head positions were not uniformly fixed, which may have affected the depth of CVC placement. Third, many studies have indicated that the insertion depth of the catheter was highly correlated with infant height^{6,7,21}; however, we did not obtain infant height data from the medical records, and were therefore unable to determine whether there was such a correlation. Fourth, we did not receive feedback from the surgeon regarding the position of the catheter during the operation; therefore, we could not verify our results with more clinical information. Finally, we only focussed on infants; our results are therefore not necessarily applicable to children of all ages. These limitations highlight the need and scope for further, preferably prospective, studies on this topic.

Conclusions

In conclusion, the fourth thoracic vertebra has potential as a radiographic landmark for the depth of catheterisation in the right internal jugular vein of infants when the carina is not visible via chest

radiography. This feature may be valuable for reducing the clinical risks associated with inappropriate CVC placement.

Abbreviations

CVC: Central venous catheter; IQR: Interquartile range; RIJV: Right internal jugular vein; SVC: Superior vena cava

Declarations

Ethics approval and consent to participate: This study was approved by the Ethics Committee of the Beijing Children's Hospital, China (No. 2020-K-015). Informed patient consent was waived due to the retrospective nature of the study.

Consent for publication: Not applicable.

Availability of data and materials: All data generated or analysed during this study are included in this published article.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: FW contributed to the overall study design, data analysis, and manuscript revision. GL helped design the study, performed the experiments, collected and analysed data, and wrote the manuscript. JZ helped design the study and revised the manuscript. HL performed the experiments and collected data. All authors read and approved the final manuscript.

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Figures

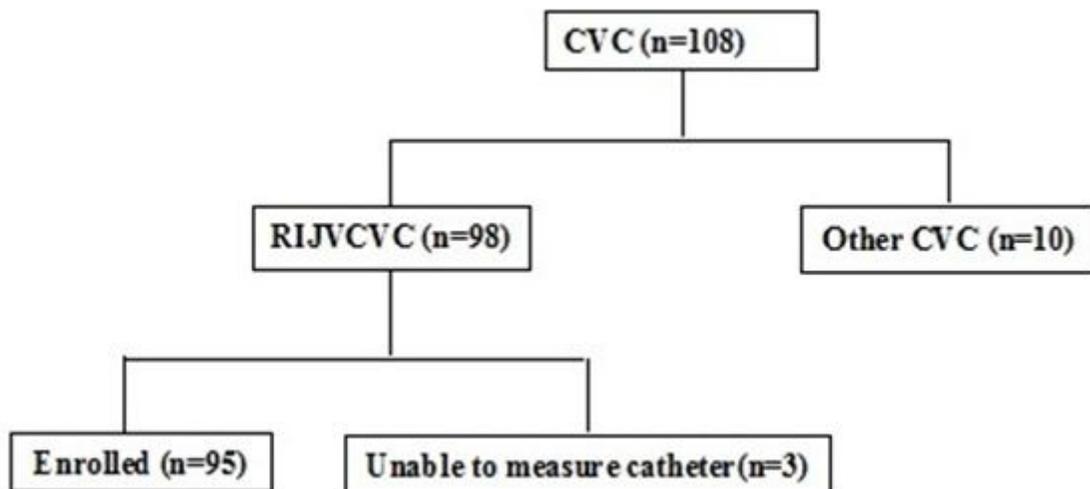


Figure 1

Details of assessed CVC cases. CVC, central venous catheter; RIJV, right internal jugular vein.

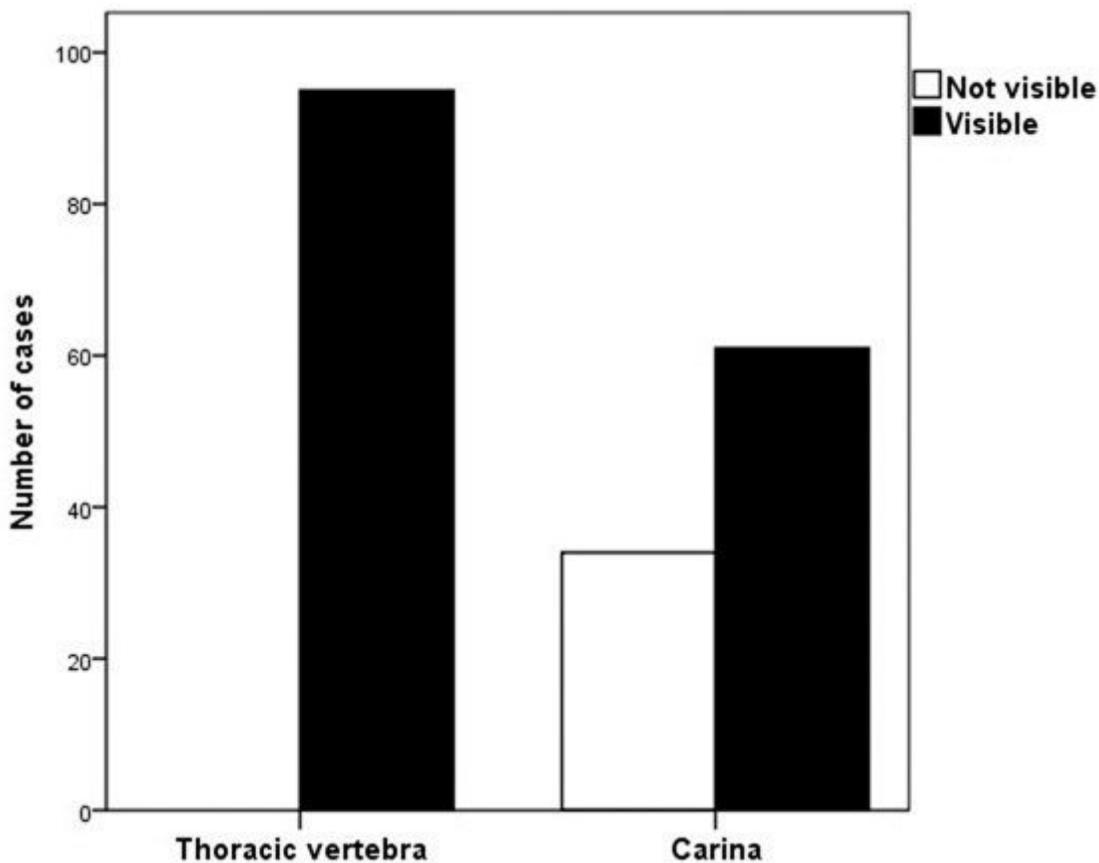


Figure 2

Comparison of the visibility of the carina and thoracic vertebra on chest radiographs. N.B.: there was a significant difference between the visibility of the carina and thoracic vertebra, $P < 0.05$

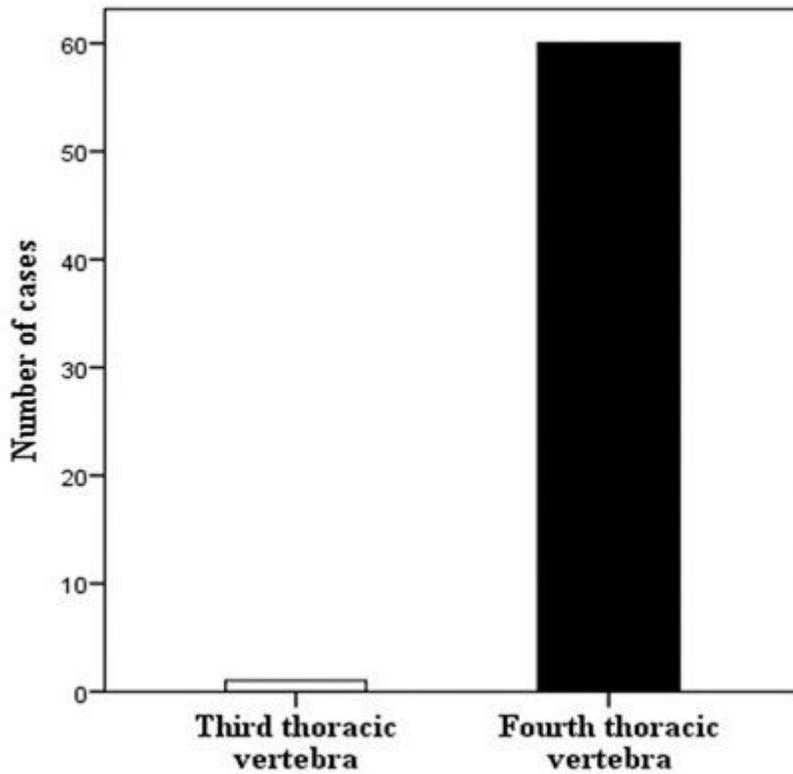


Figure 3

Positional relationship between the carina and thoracic vertebra in 61 infants. N.B.: the carina was located at the fourth thoracic vertebra more than in other locations, $P < 0.05$

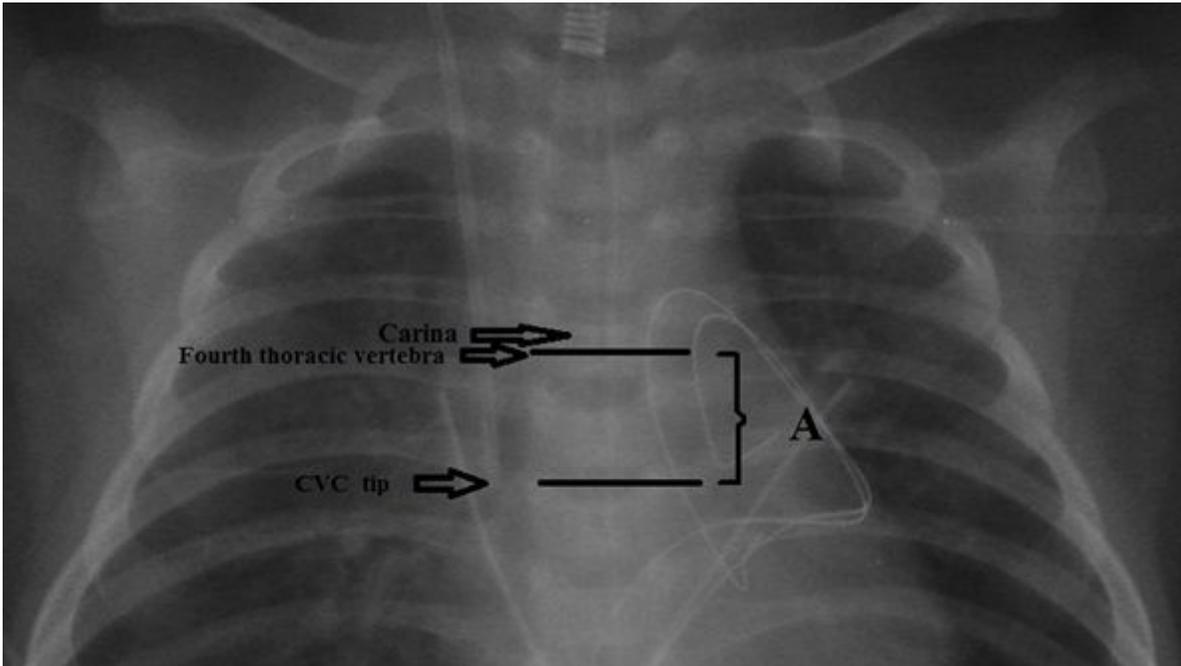


Figure 4

Measurement of vertical distance between the CVC tip and the fourth thoracic vertebra N.B.: A picture archiving and communication system was used to measure the vertical distance (A) from the transverse plane of the CVC tip to the level of the fourth thoracic vertebra. CVC, central venous catheter