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Research Article

Analysis of Factors Influencing Thoracic Deformities after Median Sternotomy in Infants Who Underwent Congenital Cardiac Surgery

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Objective. To investigate the incidence of thoracic deformities after median sternotomy in infants who underwent congenital cardiac surgery and determine its influencing factors. *Methods*. This was a single-center retrospective study. A total of 156 infants who underwent congenital cardiac surgery with median sternotomy in a provincial hospital in China from September 2020 to January 2022 were included. Depending on whether thoracic deformities occurred, the patients were classified into the thoracic deformity group and the no thoracic deformity group. Relevant data were retrieved through an electronic medical record system, and statistical comparisons and analyses were performed. *Results*. The incidence of postoperative thoracic deformities in this cohort was 10.9%. Sternal pins for auxiliary sternal fixation were used in eighty-nine infants. After analysis, it was found that age at operation (1.9 ± 0.9 vs. 3.7 ± 1.2, $P < 0.001$) and weight-for-age Z-scores (-2.0 ± 0.7 vs. -1.4 ± 0.7, $P = 0.001$) of the thoracic deformity group were significantly lower than those of the no thoracic deformity group. In addition, sternal pin use was significantly higher in the no thoracic deformity group than in the thoracic deformity group (61.9% vs. 17.6%, $P = 0.001$). Univariable analysis showed that age at operation (OR, 4.74; 95% CI, 2.38–9.46; $P < 0.001$) and weight-for-age Z-scores (OR, 4.40; 95% CI, 1.74–11.12; $P = 0.002$) were significant risk factors for postoperative thoracic deformity. Using sternal pins for auxiliary sternal fixation was an important protective factor (OR, 7.57; 95% CI, 2.08–27.59; $P = 0.003$). *Conclusions*. In this study, 10.9% of infants undergoing congenital cardiac surgery through a median sternotomy developed thoracic deformities after surgery. Younger age at operation and poor nutritional conditions may be risk factors for postoperative thoracic deformity. Sternal pin-assisted fixation has a positive effect on the prevention of thoracic deformities.

1. Introduction

Congenital heart disease (CHD) is one of the most common structural malformations in live-born infants. The prevalence of CHD is estimated to be 1.35 million per year, and the incidence of neonatal CHD is 1% [1, 2]. At present, the treatment of CHD is still dominated by surgery, and median sternotomies are the most commonly used surgical approach for CHD. However, because of the softness of the sternum due to the smaller ossified volume in infants, the likelihood of sternum deformation after median sternotomy is much higher in infants than in adults [3, 4]. Thoracic deformities often occur in infants who undergo congenital cardiac surgery with a median sternotomy, and postoperative sternal malunion may result in sternal infection, chronic osteomyelitis, or sternal deformities such as pectus carinatum [5]. According to previous studies, thoracic deformity incidence after median sternotomy in infants reaches 12% [6]. Moreover, sternal deformity after median sternotomies in infants can lead to increased psychological, physical, and socioeconomic costs of treatment.

Many institutions have recently conducted related studies on thoracic deformities after median sternotomy. Kamiya et al. found that the number of guidewires at the sternal closure significantly impacted postoperative thoracic deformity outcomes [7]. Raman et al.'s study on the stability of sternal fixation revealed that the sternum rigorously fixed with a steel plate had better healing conditions and reduced early postoperative pain compared with the sternum closed with a steel wire [8]. However, the literature includes few studies on the factors associated with thoracic deformity after median sternotomy in infants, and no one has systematically analyzed the prevalence of postoperative thoracic deformity and its potential associated risk factors in this group. Therefore, we conducted a retrospective analysis of factors influencing thoracic deformities in infants who underwent congenital cardiac surgery with a median sternotomy to identify important aspects for optimizing postoperative sternal healing.

2. Methods

This study was a retrospective study conducted at a provincial hospital in China. The hospital ethics committee approved the study, and the institutional review board approved a waiver of written informed consent.

A total of 156 infants who underwent congenital cardiac surgery with a median sternotomy between September 2020 and January 2022 were included in the study. The relevant data about the infants were collected through the electronic medical record system. Depending on whether thoracic deformities occurred, the patients were classified into the thoracic deformity group and the no thoracic deformity group. The inclusion criteria were as follows: (1) infants who underwent congenital cardiac surgery with median sternotomy in our hospital; (2) infants who recovered smoothly after the operation; (3) infants who completed the 3-month follow-up after discharge with thoracic deformity evaluated. The exclusion criteria were as follows: (1) cases with incomplete clinical data required for the study; (2) thoracic deformities were found on preoperative physical examination; (3) infants with liver/renal insufficiency or other metabolic diseases; (4) infants with other systemic diseases.

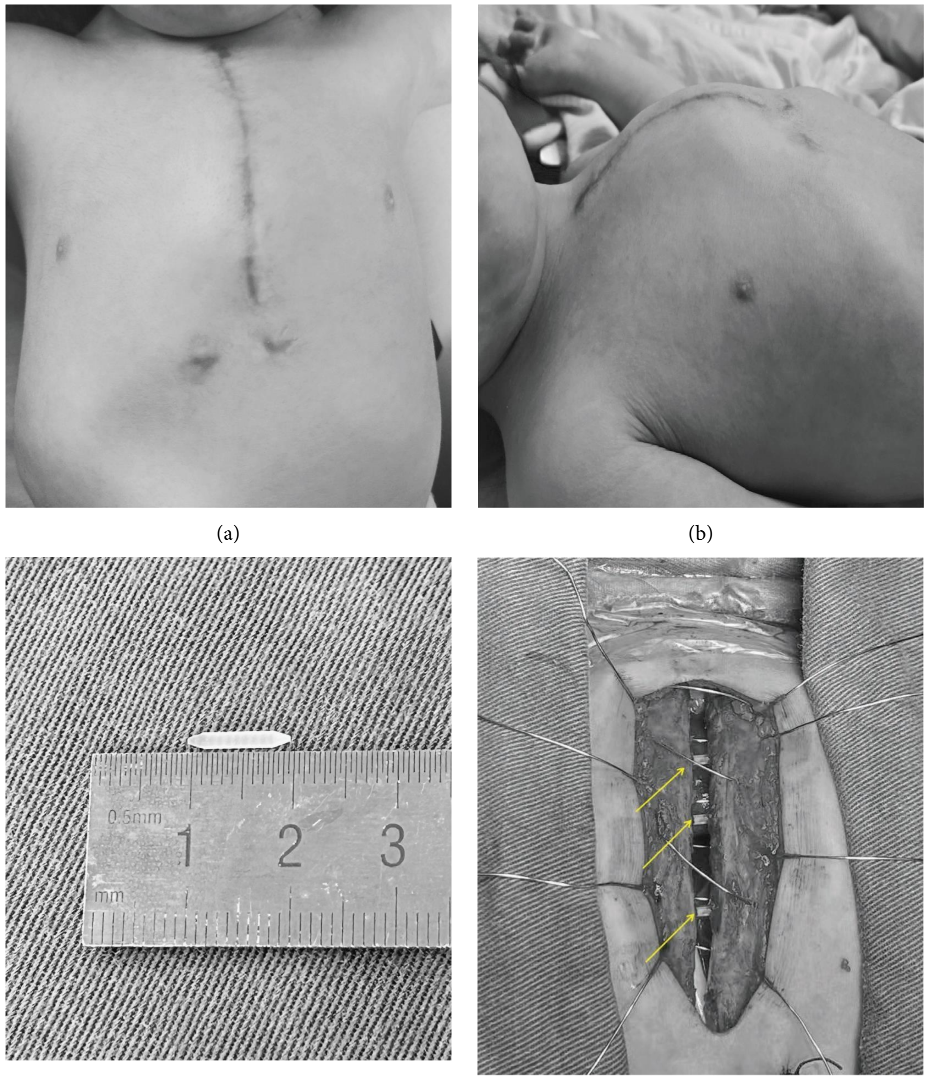
In the preoperative conversation with all the patients' parents, the surgeon advised the parents of the advantages and disadvantages of sternal pins and then asked their opinions on whether they wanted the surgeon to use sternal pins for assisted sternum closure. Finally, the use of sternal pins was decided jointly by the parents and the surgeon. At the time of sternum closure, sternal pins (GUNZE Medical Device Company, Japan) were used in 89 patients (57.1%). Thoracic deformity after median sternotomy was defined as the presence of pectus carinatum, pectus excavatum, sternal fissure, or anterior and posterior displacement of the closed sternum upon postoperative follow-up physical examination and chest CT examination [9].

In this study, the utilization rate of sternal pins in the two groups was taken as an exposure factor for sample size calculation. Combined with the results of previous literature and the clinical experience of our institution [6], we assumed that the incidence of postoperative thoracic deformities was approximately 12% and that the utilization rate of sternal pins was expected to be 26% in the thoracic deformity group and 63% in the no thoracic deformity group, with $\alpha = 0.05$ for both sides and power = 0.8. The sample size was calculated using PASS 15 (Power Analysis and Sample Size Software (2017), NCSS, LLC, Kaysville, Utah, USA). Finally, the sample size of the thoracic deformity group was 14 and the sample size of the nonthoracic deformity group was 116, so a total of at least 130 patients needed to be included in this study.

2.1. Surgical Method. All infants included in the study underwent congenital cardiac surgery with a median sternotomy. After the completion of cardiac surgery, some infants who did not choose to use sternal pins directly used wires for sternal closure. In the other group, because sternal pins were used for auxiliary fixation, we used an attachment reamer to drill three pairs of symmetrical holes in each sternal half section before wire closure, including one pair in the manubrium and the other two pairs in the sternal body. Two specifications of sternal pins were used in this study, including 1.5 mm $*$ 10 mm for patients weighing less than 10 kg and 1.5 mm $*$ 20 mm for patients weighing more than 10 kg. After the wire was placed (but not tightened), the sternal pins were inserted into the medullary hole on one side of the sternum, approximately one-third of the total length of the sternal pins, while the other third of the sternal pins were inserted into the other side of the hole of the sternum, and the wire was then tightened. Sternal closure was completed by further pulling the wire (Figure 1).

2.2. Data Collection. The age at operation, sex, weight, and weight-for-age Z-scores at discharge were collected. The Z-score for weight-for-age was calculated using the World Health Organization (WHO) reference data growth chart [10]. Clinical data such as the type of surgery, the duration of surgery, whether chest closure was delayed, the use of sternal pins, the duration of mechanical ventilation, and the length of hospital stay were also collected. The thoracic deformity condition was evaluated at 1-month and 3-month follow-ups after discharge. A concurrent chest CT examination was performed to assess the outcome of cardiac surgery and sternal healing. According to the CT reexamination images, the corresponding Haller index, and the routine physical examination, the radiologist and surgeon evaluated whether the patient had thoracic deformities. The radiological evaluators were unaware of the infants' participation in the study and the type of sternal closure performed during the operation. The information collected in this study was for research purposes, and we kept the information strictly confidential. A dedicated research assistant collected the data for this study.

2.3. Statistical Analysis. Quantitative variables were expressed as means and standard deviations (SD), while qualitative variables were expressed as frequency and percentage values (%). This study used skewness and kurtosis coefficients to analyze whether variables were normally distributed. If all measurement data conformed to a normal distribution through a normality test, an independent-sample t-test was used. Otherwise, a nonparametric test (the



(a) (b) (c) (d)

Figure 1: (a) Anterior view of an infant with thoracic deformity; (b) side view of the infant with thoracic deformity; (c) appearance of the sternal pins used in this study; (d) sternal pins were used for auxiliary sternal fixation during surgery.

Mann–Whitney test) was used for comparative analysis. The chi-square or Fisher's test was used for categorical variables between the two groups. Univariable analysis was used to measure the independent association between thoracic deformity and each relevant demographic and clinical factor. The data were treated using IBM SPSS Statistics for Windows, version 22.0 software (Armonk, NY: IBM Corp.). A significance level of $p < 0.05$ was used for the statistical tests.

3. Results

A total of 156 eligible infants were enrolled in this study, and the general information about all infants is shown in Table 1. A total of 17 infants met the criteria for postoperative thoracic deformity, and the incidence of postoperative thoracic deformities in this cohort was 10.9%. Ten of these infants experienced delayed sternal closure, and 89 used sternal pins for auxiliary sternal fixation.

Table 1: Clinical data of all infants.

Variables	Mean ± SD or percentage
Number of patients, *n* (%)	156 (100)
Age at operation (m)	3.5 ± 1.3
Male gender, *n* (%)	85 (54.5)
Weight (kg)	5.3 ± 1.0
Weight-for-age *Z*-scores	−1.5 ± 0.7
Aortic cross-clamp time (min)	57.9 ± 11.1
Cardiopulmonary bypass time (min)	94.3 ± 12.1
Duration of surgery (h)	3.6 ± 0.8
Delayed sternal closure, *n* (%)	10 (6.4)
Use sternal pins, *n* (%)	89 (57.1)
Duration of mechanical ventilation (d)	4.2 ± 1.4
Length of hospital stay (d)	12.1 ± 2.6

As indicated in Table 2, there was no significant difference in sex, aortic cross-clamp time, cardiopulmonary bypass time, surgery duration, or mechanical ventilation

Table 2: Comparison of clinical data between the two groups.

	Thoracic deformity ($n = 17$)	No thoracic deformity ($n = 139$)	P value
Age at operation (m)	1.9 ± 0.9	3.7 ± 1.2	<0.001
Male gender, n (%)	8 (47.1)	77 (55.4)	0.609
Weight-for-age Z-scores	−2.0 ± 0.7	−1.4 ± 0.7	0.001
Aortic cross-clamp time (min)	58.9 ± 9.1	57.8 ± 11.4	0.685
Cardiopulmonary bypass time (min)	93.4 ± 10.7	94.5 ± 12.3	0.722
Duration of surgery (h)	3.5 ± 0.6	3.6 ± 0.8	0.553
Delayed sternal closure, n (%)	2 (11.8)	8 (5.8)	0.298
Use sternal pins, n (%)	3 (17.6)	86 (61.9)	0.001
Duration of mechanical ventilation (d)	4.7 ± 1.3	4.1 ± 1.4	0.116
Length of hospital stay	13.2 ± 2.4	11.9 ± 2.6	0.063

duration between the thoracic deformity group ($n = 17$) and the no thoracic deformity group ($n = 139$). After analysis, it was found that the age at operation in the thoracic deformity group was significantly lower than that in the no thoracic deformity group (1.9 ± 0.9 vs. 3.7 ± 1.2, $P < 0.001$). At the same time, the weight-for-age Z-scores of the infants with thoracic deformities were also lower than those of the infants with no thoracic deformities, and the difference was statistically significant (−2.0 ± 0.7 vs. −1.4 ± 0.7, $P = 0.001$). We also found that sternal pin use was significantly higher in the no thoracic deformity group than in the thoracic deformity group (61.9% vs. 17.6%, $P = 0.001$).

Table 3 shows the results after univariable analysis. The age at operation (OR, 4.74; 95% CI, 2.38–9.46; $P < 0.001$) and weight-for-age Z-scores (OR, 4.40; 95% CI, 1.74–11.12; $P = 0.002$) were significant risk factors for postoperative thoracic deformities, while sternal pins for auxiliary sternal fixation were an important protective factor (OR, 7.57; 95% CI, 2.08–27.59; $P = 0.003$).

Table 4 shows that among the 17 infants with postoperative thoracic deformities, 7 had pectus carinatum and the other 10 had pectus excavatum. The preoperative Haller indices of the two groups were 2.44 ± 0.06 and 2.41 ± 0.05, respectively. The Haller index at 1 month after discharge was 2.16 ± 0.07 and 3.04 ± 0.11, respectively. There was no significant change in the Haller index at the 1-month and 3-month follow-up periods in the two groups.

Table 3: Univariable analysis of the different predictors of thoracic deformity.

Characteristics	OR (95% CI)	P value
Age at operation (m)	4.74 (2.38, 9.46)	<0.001
Gender, n (male%)	0.72 (0.26, 1.96)	0.516
Weight-for-age Z-scores	4.40 (1.74, 11.12)	0.002
Duration of surgery (h)	1.22 (0.64, 2.32)	0.551
Delayed sternal closure	0.46 (0.09, 2.36)	0.350
Use sternal pins	7.57 (2.08, 27.59)	0.003

Table 4: CT Haller index change of 17 patients with thoracic deformity.

CT Haller index	Preoperative	1-month	3-month
Pectus carinatum ($n = 7$)	2.44 ± 0.06	2.16 ± 0.07	2.18 ± 0.08
Pectus excavatum ($n = 10$)	2.41 ± 0.05	3.04 ± 0.11	3.03 ± 0.10

4. Discussion

This study is a retrospective analysis of the influencing factors for thoracic deformity in infants who underwent congenital cardiac surgery with a median sternotomy. The results of our study showed that the incidence of thoracic deformities after median sternotomy in infants reached 10.9%, an effect similar to that reported in the published paper by Wang et al. [11]. We found that at operation and weight-for-age, the Z-scores in the thoracic deformity group were significantly lower than those in the no thoracic deformity group. We also found that the use of sternal pins was significantly higher in the no thoracic deformity group than in the thoracic deformity group. The univariable analysis results showed that age at operation and weight-for-age Z-scores were independent risk factors for postoperative thoracic deformity, and the use of sternal pins to fix the sternum was an important protective factor.

Our study found that age at operation was an independent risk factor for thoracic deformity in infants after median sternotomy. This result was closely related to the sternal development characteristics of infants. Sternum morphology undergoes the most significant changes in infancy and childhood; breastbone ossification during infancy is low; however, from infancy to adulthood, the sternum is in the process of constant development and ossification, with the ossification center expanding to the sternum cartilage around the ossification, thus gradually increasing the stability of the sternum [12, 13]. After performing CT on children of different ages, Sandoz et al. found that the volume of the sternum was significantly associated with age [14]. On the other hand, the study by Zeitani et al. also pointed out that the thickness of the sternum was an independent predictor of thoracic deformity [4]. These findings also laterally illustrated the importance of age in poststernotomy thoracic deformities. However, many infants with CHD require surgical treatment at an early stage. Therefore, age, as a non-negligible risk factor for thoracic deformities, deserves the attention of surgeons.

A previous study on the nutritional status of infants with CHD showed that 15% of infants with CHD had moderate or severe malnutrition, and few received appropriate nutritional support [15]. This also magnified the effect of nutritional conditions on surgical recovery. Ogawa et al. pointed out that malnutrition status before surgery might be an independent predictor of delayed postoperative recovery in patients undergoing elective cardiac surgery [16]. Nutritional status was also an important factor affecting our patients' healing and thoracic deformity after sternotomy. Weight-for-age Z-scores were used to evaluate the nutritional status of infants after surgery. Univariable analysis showed that weight-for-age Z-scores were an independent predictor of postoperative thoracic deformity, and the poor nutritional status of infants at the time of surgery had a negative impact on postoperative sternal healing. After median sternotomies in adults, studies of sternal dehiscence showed that BMI was also a significant predictor. Nevertheless, the effect of BMI in adults was reflected in the negative effect of obesity [17]. The study by Zura et al. showed that wound infection was not conducive to fracture healing [18], while surgical site infections were not associated with thoracic deformity, which might also be due to the sample size.

Compared with the influence of age and weight-for-age Z-scores on thoracic deformities after sternotomy, the sternal closure method is one of the factors that can be controlled. The effect of the sternal closure method or auxiliary devices on sternal stability has been widely studied. The study by Allen et al. showed that sternotomy closure with rigid plate fixation significantly improved sternal stability compared with wire closure [19]. In this study, the effect of sternal pin fixation on thoracic deformities after sternotomy was also analyzed. We found that using sternal pin fixation could significantly improve sternal stability and reduce the incidence of thoracic deformities. This result was also similar to the conclusion of the study by Ando [20]. In this cohort, although the use of wire could provide good transverse reduction of the sternum after median sternotomy, it did not provide sufficient longitudinal reduction to reinforce sternal stability. The sternal pins could nicely complement the longitudinal stability of the wire fixation [21]. This study also confirmed that using sternal pins for sternal fixation was positive, effective, and worth promoting, especially in infants with high-risk factors for postoperative thoracic deformities.

4.1. Limitations. Although many influencing factors were considered in the design of this study, this study still had some limitations. First, this study was a single-center retrospective study, which could not prospectively collect data related to the sternal size of infants and further analyze the effect of sternal size on postoperative thoracic deformities. Second, due to the low incidence of thoracic deformities after median thoracotomy in our center, the sample size that could be included in this study was limited. The small sample size of our study limited our ability to predict risk factors for postoperative thoracic deformities to some extent. This study was mainly an exploratory study on the problem of postoperative thoracic deformity, and an exploratory analysis of the preliminary research results was carried out. In the future, we will conduct further and more targeted prospective studies on the factors found in this study to more thoroughly evaluate the influencing factors of thoracic deformities after median sternotomy in infants.

5. Conclusion

In this study, 10.9% of infants undergoing congenital cardiac surgery through a median sternotomy developed thoracic deformities after surgery. Younger age at operation and poor nutritional conditions may be risk factors for postoperative thoracic deformity. Sternal pin-assisted fixation has a positive effect on the prevention of thoracic deformities.

Data Availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Jian-Feng Liu and Hua Cao designed the study, performed the statistical analysis, participated in the operation, and drafted the manuscript. Wen-Hao Lin, Yu-Kun Chen, and Qiang Chen collected the clinical data. All the authors read and approved the final manuscript.

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