The effect of costal cartilage resection on the chest wall development: a morphometric evaluation

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Abstract

Objective: In repair of thoracic wall deformities, there is a debate in the literature regarding the optimal age and the type and number of costal cartilage resections. We evaluated the effect of costal cartilage resections on the chest wall development in young rabbits. Methods: Fifty apparently healthy, 6 weeks of age, male New Zealand white rabbits were evaluated in five groups, each including 10 subjects. Group 1 served as control for the observation of normal thoracic development. Rabbits in group 2 underwent partial and rabbits in group 3 underwent total resections of the right third and fourth costal cartilages; those in group 4 underwent partial and rabbits in group 5 underwent total resections of the right third to sixth costal cartilages. Anteroposterior, horizontal and vertical diameters of the chest were measured before operation and repeated at 24 weeks of age. Results: Upper and lower anteroposterior diameters of the thoracic wall and horizontal diameters of the left hemithorax differed significantly among groups (p = 0.011, p = 0.004, and p = 0.002, respectively). Upper anteroposterior diameter was 49 mm in group 1 and 44 mm in group 3 (p = 0.009). Lower anteroposterior diameter in group 5 (66 mm) was significantly less than that in group 1 (70 mm) (p = 0.039) and there was also a statistically significant difference between group 4 (71 mm) and group 5 (66 mm) (p = 0.002). Horizontal diameters of the left hemithorax in group 3 (32 mm; p = 0.005) and 5 (32 mm; p = 0.008) were significantly different when compared to group 1 (26 mm). Growth in right hemithorax was statistically less than that in left side in all operated groups except in group 2. Conclusions: Thoracic resections in young rabbits have demonstrated that the costal cartilage resection is not an innocent procedure as it severely affects the chest wall development especially in anteroposterior direction and the thoracic growth is markedly retarded when growth centers of the ribs are not preserved and/or four or more ribs are resected.

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1. Introduction

Thoracic wall deformities may be either congenital or acquired. Congenital thoracic wall deformities affect about 1% of the population [1–3]. The most common thoracic deformities are pectus excavatum and pectus carinatum. Surgical indications for congenital thoracic deformities are mainly cosmetic and psychological anxieties, and sometimes cardiopulmonary complications due to a mechanical compression caused by the lower positioned sternum [2]. Operation techniques developed for thoracic repair have focused on the correction of external appearance of sternocostal deformities and the cosmetic results of such operations are very successful, reducing psychosocial trauma that may emerge in these patients [1–3]. As known, children with thoracic deformities become progressively more self-conscious during adolescence and show an unwillingness to expose the chest while doing sportive exercises such as swimming or athletic activities [1]. Psychological disturbances ranging from hypochondriasis to a tendency to suicide have been reported in adults, between the ages of 18 and 35, who had no correction operations [4]. Therefore early operation is supported in these patients reducing likely psychological complications to a minimum [2,5–7]. However, there is still debate in the literature regarding the optimal age for surgical repair [1,2,5,8]. If not urgent, some prefer to operate after completion of the thoracic growth in view of the fact that recurrence would be less common [9].

Treatment of thoracic deformities may sometimes need a resection of costal cartilage [1–3,10–12]. Until the Nuss procedure, known as minimally invasive technique, was defined the majority of pectus excavatum repair were accomplished using a technique suggested by Ravitch [10] in 1949 including subperichondrial resection of all deformed cartilages, posterior sternal osteotomy, xiphoid excision and anterior fixation of the sternum without prosthesis.
However, the results of the reports were not comparable because of the wide variety of modified techniques used [8,13–15]. Although such operations correct sternal deformities the impact of costal cartilage resections on the chest wall development is not well-documented. In this study, we investigated the influence, if any, of the type and number of costal cartilage resections on the chest wall development. For this purpose, we made an experimental model to assess the qualitative and quantitative effects of costal cartilage resections in young rabbits.

2. Materials and methods

Fifty male, 6 weeks of age, New Zealand white rabbits were used. All animals received humane care in compliance with the European Convention on Animal Care. This experimental study was approved by institutional ethics committee.

2.1. Groups

The subjects were divided into five groups, each containing 10 rabbits. Group 1 served as control and normal thoracic wall development without costal cartilage resection was observed. Costal cartilage resections were carried out in all rabbits of the remaining groups. Group 2 underwent partial resections of the third and fourth costal cartilages. Group 3 underwent total resections of the same costal cartilages. The rabbits in group 4 underwent partial resections of the third, fourth, fifth and sixth costal cartilages and the rabbits in group 5 underwent total resections of the same cartilages. Cartilage resections were only performed on the right side. While costochondral junctions were saved in partial resections they were removed in total resections. The internal three-fourths of the costal cartilages were removed in partial resections.

2.2. Physiological measurements

Before the operation the rabbits were numbered and weights were noted in grams. Blood samples for arterial blood gas measurements were taken from the ear artery in the room air and PaO$_2$, PaCO$_2$, pH and SaO$_2$ were noted.

2.3. Morphometric measurements

Anteroposterior and lateral chest roentgenograms of each rabbit were taken. Morphometric thoracic measurements of the subjects were performed using reference points demonstrated in Fig. 1A and B. Reference points for morphometric measurements were modified from previously published Welch index [16] and the state of costal cartilage resections (e.g. while D1 reflects unresected site, D2 indicates the site of first resected costal cartilage) (Table 1).

2.4. Anesthesia

General anesthesia was induced by Ketamine HCl 15–20 mg/kg i.v. or 20–25 mg/kg i.m. and maintained by Xylazine 0.5–1 mg/kg i.v. or 1–2 mg/kg i.m. If needed, same dosages of Ketamine HCl and Xylazine were repeated. The mean anesthesia time was 7–10 min for each rabbit. All subjects were given Ceftazidime Pentahydrate 50 mg/kg i.m. for the purpose of infection prophylaxis.

2.5. Operation technique

Median chest incision was carried out in supine position. The costal cartilages were exposed via dissection of pectoral
Depression degree (Depression ratio 0.74) Angle (θ)

PaCO₂ (mmHg) 32 ± 4
PaO₂ (mmHg) 83 ± 13
SaO₂ (%) 95
PaCO₂ (mmHg) 48 ± 6
D1 (mm) 34 ± 6
D2 (mm) 35 ± 6
D3 (mm) 40 ± 6
D4 (mm) 47 ± 6
D5 + D6 (mm) 21 ± 2
Angle (θ) 19 ± 3
Depression ratio 0.74 ± 0.04
Depression degree (θ) 2.6 ± 0.4
Index (θ) 2.6 ± 0.4

3. Results

The physiological and morphometric parameters of the rabbits measured at the sixth week did not differ among groups (Table 2).

Table 3 summarizes the mean ± standard deviation of the physiological and morphometric parameters measured at the twenty-fourth week. There were statistically significant differences for D2, D3 and D6 among groups (p < 0.05). Significant growth retardation was present especially in group 5. The value of D3 in group 5 was significantly less than that in group 1 (p = 0.039) and there was also a statistically significant difference between group 4 and group 5 (p = 0.002). D2 also showed a significant difference between groups 1 and 3 (p = 0.009). There was also a difference, however, not statistically significant, between groups 1 and 5 (p = 0.073).

No statistical difference was noted for D4 indicating vertical chest diameter.

D5 for the right hemithorax was decreased; however, the difference did not reach statistical significance. In contrast, symmetrical D6 for the left hemithorax was increased in all groups. D6 in group 3 (p = 0.005) and 5 (p = 0.008) was significantly different when compared to group 1 (control).

As shown in Table 4, the right to left diameters of both hemithoracis at the twenty-fourth week was compared with...
each other to assess the effect of costal cartilage resection on the chest wall development in horizontal axis. Growth in right hemithorax remained behind that of left hemithorax in all operated groups except group 2 and it was statistically significant.

In groups where resections were carried out, a disturbance in sternal shape associated with the direction of the force was observed (Fig. 2). The values of Welch index, which shows sternal depression ratio and degree against lateral dislocation, is less than 5 in all groups compared to that in control.

### Table 4
Comparison of the diameters of right (D5) and left (D6) hemithoracis of each rabbit within groups

<table>
<thead>
<tr>
<th>Group</th>
<th>t value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (control)</td>
<td>1.000</td>
<td>0.342</td>
</tr>
<tr>
<td>Group 2</td>
<td>-1.703</td>
<td>0.123</td>
</tr>
<tr>
<td>Group 3</td>
<td>-4.247</td>
<td>0.002</td>
</tr>
<tr>
<td>Group 4</td>
<td>-4.993</td>
<td>0.001</td>
</tr>
<tr>
<td>Group 5</td>
<td>-4.129</td>
<td>0.003</td>
</tr>
</tbody>
</table>

### 4. Discussion

Costal cartilage resections carried out for the repair of thoracic wall deformities especially during childhood may have a negative effect on the thoracic growth. This experimental study was planned to assess the effects of repair operations of sternocostal deformities on the chest wall development, and to present those dimensions in which cartilage resections affect the thoracic growth.

It has been shown that the cartilage resection affected the chest wall development especially in anteroposterior dimension as evidenced by the fact that D3 (measured at the level of xiphoid) has decreased especially in group 5 and D2 (measured at the level of resected cartilage) has decreased both in groups 3 and 5 compared to that in control although D1 (measured at the level of unresected cartilage) did not differ significantly among groups. It may be considered that cartilage resections, either partial or total, have affected the growth and development of the thoracic cage in anteroposterior dimension. Martinez et al. also reported decreased anteroposterior diameter of the chest after costal cartilage resections in their study [12].

Horizontal growth retardation in the right hemithorax where resection was carried out was not significantly evident among operated groups when compared to each other and control although D5 has shown to decrease in all operated groups. It may suggest that neither the number of resected ribs nor saving growth centers of the ribs may have a substantial effect on the development of resected hemithorax in horizontal direction. In contrast, the left hemithorax diameter (D6) increased in all operated groups. Statistically significant increases were seen especially in groups 3 and 5 compared to control. It is seen that the unresected hemithorax compensates the growth retardation that may occur in the resected hemithorax.

When the diameter of right and left hemithoracis of each rabbit was compared to each other the right hemithorax development compared to left retarded in all operated groups except in group 2 and the difference was statistically significant. It seems that the horizontal growth is affected when the number of costal cartilage resection is increased and/or the growth centers are unsaved.

'S' shaped sternal rotation is characterized by its pushing towards the resected site. The rotation of the sternum might not be so prominent if a supportive material had been used in this experiment. The insignificant change in index may be explained by normal thoracic development as a result of saved first and second, and seventh and eighth costal cartilages showing close association of sternal depression with the alteration in the seventh and eighth costochondral area. All these findings show that the costal cartilage resection is not so innocent, as also emphasized by Martinez et al. [12].

It has been suggested that the scar tissue that forms in the cartilage beds inside the perichondrium following cartilage resections may interfere with the cartilage growth and also the chest wall development. Martinez et al. [12] explained this situation by disruption of the growth centers of costal cartilages. Both Weber and Kurckhubasche [18] and Haller et al. [19] reported restrictive pulmonary disease due to the asphyxiating thoracic dystrophy after pectus repair. Croitoru et al. [20] observed scarification and ossification, to varying degrees, of the cartilage bed not detected on plain chest X-rays and only visible on chest CT scan in 59% of the patients previously operated for thoracic deformity and who had a recurrence of the deformity during the follow-up period and also reported that several patients had acquired thoracic chondrodystrophy with poor growth of the chest wall.

There is no consensus in the literature regarding the optimal age for surgical repair of congenital thoracic deformities [1,2,21,22]. Most advocate early operations in childhood either because of psychological reasons or of easy applicability of the surgical technique. However, the most common frightening complication after such operations in this period is recurrence [19,23]. Recurrence rates after

![Fig. 2. 'S' shaped sternal deformity at the twenty-fourth week was disclosed in axial three-dimensional computed tomography of the chest taken only in a subject for demonstration.](https://academic.oup.com/ejcts/article-abstract/32/5/756/373158)
repair operations are reported to be anywhere from 2% to 37% [20,23]. There may be other causes of recurrence besides operation in early childhood. These are: Marfan’s syndrome, extensive dissection, early removal or non use of the sternal bar, and local infections [23–25]. Martinez et al. [12] especially emphasized chest growth retardation as the most frequent complication instead of recurrence after repair operations. As seen in our experimental study, a significant disturbance in growth and development was also seen in groups where growth centers of the ribs were resected. This finding supports avoidance of aggressive surgery in chest wall resections in early childhood. Instead, resection should be minimal and the costochondral junction, growth center of the rib, should be saved. In accordance with these findings, a surgical technique not employing costal cartilage resection, and/or, if performed, replacement of costal cartilages, should be improved.

Thoracic resections employed in young rabbits, which had incomplete bone maturation have demonstrated that; (1) the costal cartilage resection is not an innocent procedure. The chest wall growth and development are severely affected especially in anteroposterior direction. (2) The chest growth is markedly retarded when growth centers of the ribs are not preserved and/or four or more ribs are resected. (3) Sternum is relatively affected from cartilage resections, as well; however, the type of influence is as sternal rotation instead of sternal depression. Such a deformity may be explained by normal maturation of the second and seventh ribs that fix sternum at the upper and lower edges.

In the light of our findings, two factors should be considered if chest wall resections are to be performed early in childhood: first is saving the growth center of the ribs at costochondral junctions, second is limiting or minimizing, if any possible, the number of costal cartilages resected.

References