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Costal Cartilages Do Not Overgrow in Patients with Pectus Excavatum

Vlad-Laurentiu David[a] Simona Cerbu[d] Horia Haragus[b] Marius-Calin Popoiu[a]
Corina-Maria Stanciulescu[a] Gabriel Cozma[c] Ovidiu Burlacu[c] Eugen-Sorin Boia[a]

[a]Department of Pediatric Surgery, [b]First Clinic of Orthopedics and Trauma and [c]Department of Thoracic Surgery, 'Victor Babes' University of Medicine and Pharmacy, and [d]Department of Imagistics, Emergency Children's Hospital 'Louis Turcanu', Timisoara, Romania

Key Words
Pectus excavatum · Costal cartilage · Overgrowth · Cartilage length

Abstract
Objective: The purpose of this study was to determine whether or not patients with pectus excavatum (PE) exhibit costal cartilage overgrowth compared to normal subjects. ***Materials and Methods:*** The computed tomography acquisitions of 32 patients with PE and 35 normal controls were analyzed. On axial images the length of the 4th–7th costal cartilages was measured to calculate the Haller index. The ratio between the length of the cartilages and the median of the transverse and longitudinal thorax diameters were recorded to account for anatomical variability. The length of the cartilages was compared between the PE and control subjects using the independent-samples t test. For patients with asymmetric PE the length of the 4th–7th costal cartilages was compared between the rotated and nonrotated sides. ***Results:*** The mean transverse and coronal thorax diameters were 233.29 ± 24.47 and 231.69 ± 22.47 mm for PE patients and 252.67 ± 37.25 and 238.64 ± 27.40 mm for controls, respectively, with no significant differences between the two groups (p = 0.816 and 0.145). The mean sagittal diameter (59.30 ± 14.21 mm) and Haller index (4.02 ± 1.34) in the PE group were significantly different from the controls (107.34 ± 19.59 and 2.2 ± 0.54 mm, respectively; p = 0.00). Actual and relative lengths of costal cartilages were similar in both PE subjects and controls for all 4 costal cartilages measured. In subjects with asymmetric PE, both relative and absolute costal cartilage lengths were similar on the rotated and nonrotated side. ***Conclusions:*** The length of the 4th, 5th, 6th and 7th costal cartilages was similar in PE patients and the control subjects. These was also similar between the rotated and nonrotated sides of the sternum in patients with asymmetric PE.

Introduction

The etiology of anterior chest wall deformities so far remains elusive. Overgrowth of the costal cartilages is the most popular etiopathogenic theory. It is based on studies demonstrating an intrinsic disturbance of the costal cartilages in patients with pectus excavatum (PE) [1–3]. Nevertheless, a direct link between the histologic disturbances of the costal cartilages and the overgrowth of the cartilages has not been demonstrated [2]. However, it has been

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Eugen-Sorin Boia
Department of Pediatric Surgery, 'Victor Babes' University of Medicine and Pharmacy
2 Eftimie Murgu
RO–300041 Timisoara (Romania)
E-Mail chirpedmin@gmail.com

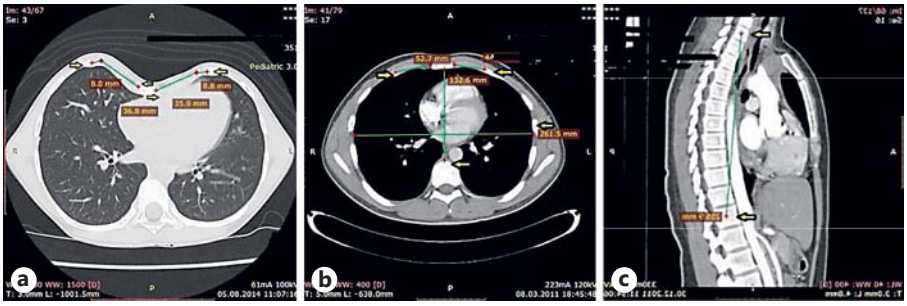

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Fig. 1. Measurement of the length of the costal cartilages and the transverse and sagittal diameters in PE patients (**a**) and controls (**b**). **c** Measurement of the height of the thorax.

postulated that the disturbance of the costal cartilage leads to reduced strength of the costal cartilage and not to overgrowth, and therefore the inward bending of the sternum is caused by diaphragm traction [4].

This study was based on the concept that in patients with PE the overgrowth of the costal cartilage could produce not only the inward bending of the sternum, but also longer cartilages than in normal subjects. Therefore, the aim was to compare the length of the costal cartilages of patients with PE versus normal subjects.

Materials and Methods

A total of 67 subjects were enrolled in this study. These included 32 patients with PE and 35 subjects without chest wall malformations that underwent a chest computed tomographic (CT) examination for other pathological conditions. The PE group consisted of 15 female and 17 male patients with an age range of 8–22 years. The mean age of the PE group was 14.82 ± 3.93 years. The control group consisted of 15 female and 20 male patients with an age range of 9–20 years and mean age of 13.80 ± 2.94 years. All subjects were investigated prior to any surgical intervention. The CT scanning was performed with the patients in a supine position, during inspiration and without contrast enhancement. Either the Siemens SOMATOM Sensation 64 or Toshiba Aquilion CXL 64 machine was used. The images were acquired at a thickness of 0.5 mm. The CT images were retrieved and analyzed using eFilm Lite v3.1.

On axial images the length of the 4th, 5th, 6th and 7th costal cartilages was measured (fig. 1a, b). Because 2D images were used, the length of the cartilages was considered from the costochondral junction to the edge of the sternum on the same side. On the same plane, at the level of the 5th costal cartilage, the transversal and the sagittal diameters were measured to calculate the Haller index. On the sagittal images, the height of the thorax was measured from the middle of the first thoracic vertebral body to the middle of the 12th thoracic vertebral body (fig. 1c). In order to surpass the variability related to normal anatomical and anthropometric individual differences, a process of normalization of the length of the costal cartilages was used. First, the median of the transverse and longitudinal diameters of the thorax was calculated for each subject. Then the measured length of the costal cartilages was divided by this median value. The formula used was: relative cartilage length = actual cartilage length/(transverse diameter of the thorax + coronal diameter of the thorax)/2. The sagittal diameter was deliberately excluded because it is directly related to the disease. As this is not a standard technique, it was validated through the use of Pearson's correlation factor.

For the PE group, patients with asymmetric PE were selected and the length of the 4th, 5th, 6th and 7th costal cartilages between the rotated and nonrotated sides of the sternum was compared, while the symmetrical ones were assumed to be similar on both sides

Statistical Analysis

The unpaired t test was used with a significance threshold set at p = 0.05 for 95% CI. To validate the process of normalization of the length of the costal cartilages, the correlation between cartilage length, thoracic diameters and the age, height and weight of the patients was calculated using Pearson's product-moment correlation coefficient.

Table 1. Diameters of the thorax cavity

	PE, mm	Controls, mm	p value
Transverse	233.29±24.47 (183.50–265.50)	231.69±22.47 (195.10–283.80)	0.816
Coronal	252.67±37.25 (180.00–304.30)	238.64±27.40 (196.1–282.90)	0.145
Sagittal	59.30±14.21 (24.60–80.60)	95.40±19.59 (53.8–126.6)	0.00
Haller index	4.20±1.34 (3.23–8.46)	2.52±0.54 (1.89–3.76)	0.00

Values are the mean ± SD with the range in parentheses.

Results

The age and gender distributions were similar in both groups with no significant differences (p = 0.974 and 0.307, respectively). The mean height of the patients in

Table 2. Pearson's product-moment correlation coefficients for the PE group

	Age		Weight		Height		Gender	
	correlation coefficient	p value	correlation coefficient	p value	correlation coefficient	p value	correlation co-efficient	p value
DT	0.701	0.000	0.781	0.000	0.777	0.000	0.150	0.474
DS	0.212	0.309	0.664	0.000	0.503	0.010	0.157	0.453
DC	0.664	0.000	0.686	0.000	0.704	0.000	0.151	0.471
C4 left	0.481	0.015	0.447	0.025	0.508	0.009	0.068	0.747
C4 right	0.435	0.030	0.452	0.023	0.619	0.001	0.193	0.354
C5 left	0.296	0.151	0.351	0.086	0.478	0.016	0.313	0.128
C5 right	0.227	0.276	0.385	0.057	0.482	0.015	0.254	0.221
C6 left	0.292	0.250	0.427	0.033	0.610	0.001	0.266	0.198
C6 right	0.239	0.250	0.427	0.033	0.910	0.001	0.266	0.198
C7 left	0.387	0.056	0.481	0.015	0.604	0.001	0.179	0.393
C7 right	0.307	0.136	0.366	0.072	0.536	0.006	0.184	0.378
Haller	0.046	0.829	–0.050	0.813	–0.153	0.465	–0.064	0.761
R4 left	–0.184	0.480	–0.234	0.261	–0.213	0.307	–0.031	0.883
R4 right	–0.81	0.699	–0.125	0.553	0.081	0.699	0.135	0.521
R5 left	–0.215	0.301	–0.225	0.279	–0.085	0.685	0.235	0.259
R5 right	–0.279	0.176	–0.184	0.377	–0.081	0.699	0.224	0.281
R6 left	–0.301	0.144	–0.258	0.213	–0.123	0.559	0.224	0.281
R6 right	–0.376	0.064	–0.232	0.264	–0.021	0.921	0.179	0.392
R7 left	–0.246	0.236	–0.212	0.310	–0.068	0.745	0.072	0.734
R7 right	–0.300	0.145	–0.302	0.142	–0.103	0.626	0.088	0.675

DT = Transverse diameter of the thorax; DS = sagittal diameter of the thorax; DC = coronal diameter of the thorax; C# = actual length of the costal cartilage; R# = relative length of the costal cartilage.

the PE group was 160.73 ± 22.82 cm (range 110–210) and in the control group was 153.96 ± 13.56 cm (range 128–178). The mean weight was 48.14 ± 15.7 kg (range 25–88) in the PE group and 49.4 ± 13.86 kg (range 27–80) in the control group. There were significant differences between the groups for height and weight (p = 0.209 and 0.771, respectively).

The mean of the transverse thoracic diameter was 233.29 ± 24.47 mm for PE subjects and 231.69 ± 22.47 mm for the controls, while the mean coronal diameter was 252.67 ± 37.25 mm for the PE group and 238.64 ± 27.40 mm for the control group, with no statistical differences between them (p = 0.816 and 0.145, respectively). The mean sagittal diameter in the PE group was 59.30 ± 14.21 mm, which was significantly lower than the 95.40 ± 19.59 mm of the control group (p = 0.00). A statistically significant difference was also found for the Haller index, which was 4.22 ± 1.34 for PE subjects and 2.52 ± 0.54 for the controls (p = 0.00; table 1).

Pearson's product-moment correlation coefficients for each group are recorded in tables 2 and 3. For the PE group we found linear correlations between all three thoracic diameters with the height and weight of the patients. The measured lengths of the cartilages correlated with the height and weight of the patients (table 2). None the relative lengths of the costal cartilages correlated with the weight and height of the patients from the PE group (p > 0.05). The actual and relative lengths of the costal cartilages were similar between the PE subjects and controls for all 4 of the costal cartilages measured, as shown in table 4.

For the control group the transverse and coronal thoracic diameters correlated with the age, weight and height of the subjects, while the sagittal diameter correlated only with the height (table 3). The actual length of all costal cartilages correlated with the height of the subjects, while only the actual length of the 4th, 6th and 7th left cartilages correlated with the weight of the subjects from the control group. Regarding the age of the controls, only the actual length of the 5th cartilage of both sides revealed a linear correlation. None of the relative lengths of the costal cartilages correlated with age, height or weight (p > 0.05).

Table 3. Pearson's product-moment correlation coefficients for the control group

	Age		Weight		Height		Gender	
	correlation coefficient	p value	correlation coefficient	p value	correlation coefficient	p value	correlation coefficient	p value
DT	0.651	0.001	0.786	0.000	0.798	0.000	0.271	0.223
DS	0.124	0.124	0.461	0.031	0.469	0.028	–0.001	0.998
DC	0.740	0.000	0.891	0.000	0.845	0.000	0.128	0.569
C4 left	0.295	0.183	0.591	0.004	0.535	0.010	0.430	0.042
C4 right	0.295	0.150	0.438	0.042	0.475	0.025	0.422	0.050
C5 left	0.318	0.033	0.583	0.004	0.490	0.021	0.500	0.018
C5 right	0.455	0.033	0.613	0.002	0.547	0.008	0.315	0.153
C6 left	0.359	0.101	0.574	0.005	0.519	0.013	0.689	0.000
C6 right	0.237	0.288	0.485	0.022	0.434	0.044	0.528	0.012
C7 left	0.355	0.105	0.563	0.006	0.602	0.003	0.468	0.028
C7 right	0.231	0.300	0.438	0.041	0.445	0.038	0.295	0.183
Haller	–0.115	0.610	–0.103	0.647	–0.228	0.307	0.212	0.344
R4 left	–0.480	0.024	–0.312	0.157	–0.376	0.085	0.244	0.273
R4 right	–0.294	0.185	–0.298	0.178	–0.301	0.173	0.192	0.392
R5 left	–0.046	0.839	–0.019	0.932	–0.119	0.598	0.437	0.042
R5 right	–0.050	0.824	–0.019	0.935	–0.058	0.797	0.201	0.369
R6 left	–0.345	0.116	–0.260	0.242	–0.327	0.138	0.553	0.008
R6 right	–0.419	0.052	–0.291	0.189	–0.358	0.102	0.367	0.093
R7 left	–0.311	0.159	–0.190	0.398	–0.92	0.685	0.348	0.113
R7 right	–0.352	0.109	–0.238	0.296	–0.226	0.311	0.171	0.448

DT = Transverse diameter of the thorax; DS = sagittal diameter of the thorax; DC = coronal diameter of the thorax; C# = actual length of the costal cartilage; R# = relative length of the costal cartilage.

Table 4. Absolute and relative lengths of the costal cartilages in PE subjects versus controls

	PE subjects (n = 32)		Controls (n = 35)		p value
	actual length, mm	relative length, mm	actual length, mm	relative length, mm	
C4 left	46.41±6.00 (37.30–58.90)		46.73± 5.30 (32.10–55.30)		0.850
		0.191±0.023 (0.146–0.240)		0.200±0.023 (0.159–0.256)	0.239
C4 right	46.63±6.73 (34.0–62.60)		46.06±6.58 (31.80–56.60)		0.772
		0.192±0.033 (0.120–0.274)		0.195±0.021 (0.157–0.234)	0.686
C5 left	63.91±12.48 (45.10–88.90)		62.28±8.69 (47.10–78.70)		0.603
		0.263±0.044 (0.180–0.341)		0.265±0.035 (0.200–0.342)	0.906
C5 right	64.14±12.90 (45.80–90.00)		62.10±8.72 (45.10–76.90)		0.524
		0.264±0.047 (0.183–0.334)		0.264±0.035 (0.190–0.334)	0.964
C6 left	76.13±10.78 (59.90–100.50)		77.86±8.76 (59.90–91.00)		0.566
		0.315±0.044 (0.231–0.407)		0.331±0.038 (0.245–0.441)	0.192
C6 right	75.01±11.13 (54.50–99.40)		77.66±9.64 (57.80–93.20)		0.387
		0.310±0.046 (0.208–0.409)		0.330±0.035 (0.270–0.417)	0.112
C7 left	92.75±14.78 (70.40–126.00)		96.23±11.24 (70.60–109.90)		0.366
		0.384±0.050 (0.300–0.497)		0.409±0.039 (0.349–0.517)	0.071
C7 right	90.68±15.42 (69.20–117.50)		94.52±11.90 (67.40–108.60)		0.342
		0.375±0.058 (0.264–0.497)		0.402±0.042 (0.333–0.516)	0.081

Values are the mean ± SD with the range in parentheses.

Table 5. Length of rotated costal cartilages compared to the nonrotated side

	Rotated side		Nonrotated side		p value
	absolute length, mm	relative length, mm	absolute length, mm	relative length, mm	
C4	46.20±7.25		48.00±6.73		0.473
		0.189±0.035		0.195±0.021	0.581
C5	65.75±12.11		66.81±13.21		0.814
		0.267±0.042		0.271±0.045	0.821
C6	74.33±11.17		76.06±11.77		0.673
		0.303±0.048		0.309±0.042	0.716
C7	88.30±15.41		90.70±15.74		0.665
		0.360±0.053		0.368±0.045	0.655

Values are the mean ± SD.

The chest deformity was asymmetric in 23 patients with the sternum facing left in 16 and right in 7 patients. Of the 32 patients (96.9%), 31 had a cup-shaped deformity and the remaining patient had a saucer-shaped deformity of the chest wall. Both the absolute and relative lengths of the costal cartilages on each side of the sternum were similar on the rotated and nonrotated sides (table 5).

Discussion

The results of this study did not reveal any difference between the length of the last 4 costal cartilages in patients with PE and normal subjects. Neither absolute nor the relative lengths of the cartilages were significantly different. Previous authors have postulated that the costal cartilage experiences an overgrowing pattern that is more pronounced during a child's period of rapid growth (growth spurt) [1, 2]. The presumption is that costal cartilages are growing excessively compared to the rest of the rib cage, putting pressure on the sternum and forcing it to bend backward [3]. Based on this well-accepted concept we designed our study to look at costal cartilage dimensions to see if PE patients exhibit overgrowth when compared to their control counterparts. The present study found no such discrepancies, thus making the costal cartilages overgrowth theory very improbable [1]. Nakaoka et al. [5] compared the actual length and the cartilage/rib ratio of the 5th and 6th costal cartilages in PE patients with normal subjects. Like us, they found a similar length for the 5th costal cartilage on both sides, but found a shorter left 6th cartilage in PE patients compared to healthy controls. In our study, the only differences between the PE patients and controls were regarding the sagittal diameter of the thorax and the Haller index. Similar results were published for patients with pectus carinatum deformity of the anterior chest wall [6, 7].

The correlation between the thoracic diameters and the absolute length of the costal cartilages with the age, height and weight of the subjects revealed that all of them increase linearly in both PE and non-PE subjects. On the other hand, the relative length of the costal cartilages does not correlate with the age, height or weight of the patients, indicating that we have successfully eliminated these constitutional variables from comparison through the normalization process. It is well known that in PE patients both the structure and the length of the adjacent rib may be affected [8, 9]. For this reason we preferred to report the actual length of the cartilages to the mean of the transverse and coronal diameters of the rib cage. In this way we could compare the lengths of the cartilages considering simultaneously the individual constitutional factors.

We further compared the length of the costal cartilages between the rotated and nonrotated side in asymmetric PE patients. The results showed no difference between the lengths of the 4th, 5th, 6th and 7th cartilages on each side of the sternum. This was a predictable outcome considering that the lengths were the results of the comparison between PE and normal subjects. We therefore disagree with Nakaoka et al. [10], who found differences between the lengths of the 5th and 6th costal cartilages from the rotated and nonrotated sides of asymmetric pectus deformity patients. The fact that they included only 12 patients in their study may be an important source for error. On the other hand, the comparison between the lengths of cartilages between the sides of the

sternum may be irrelevant, even in patients with an asymmetric deformity of the anterior chest wall. This is why we considered that the only relevant approach was to compare the length of the costal cartilages between patients with PE and patients with no deformity of the chest wall.

Conclusion

The lengths of 4th, 5th, 6th and 7th costal cartilages were similar in PE patients and normal subjects. These were also similar between the rotated and nonrotated sides of the sternum in patients with asymmetric PE. Thus, these findings could indicate that costal cartilage overgrowth cannot be a main causative factor for PE.

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