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STERNUM TOMOGRAPHIC EVALUATION IN PECTUS PATIENTS: ANALYSIS OF SAGITAL PARAMETERS

AVALIAÇÃO TOMOGRÁFICA DE PACIENTES COM PECTUS: NOVOS ÍNDICES E ÂNGULOS SAGITAIS

Davi de Podestá Haje[1,2], *Kelsen de Oliveira Teixeira*[2], *Moacir Silva Neto*[3], *José Batista Volpon*[4], *Paulo Sergio Mendlovitz*[5], *Paulo Dolabela Vasconcelos*[6]

1. Centro Clínico Orthopectus, Brasília, DF, Brazil.
2. Hospital de Base do Distrito Federal, Secretaria de Estado da Saúde do Distrito Federal, Brasília, DF, Brazil.
3. Life Check-Up Medicina Esportiva Avançada, Brasília, DF, Brazil.
4. Universidade de São Paulo, Ribeirão Preto Medical School, Ribeirão Preto, SP, Brazil.
5. Sabin Medicina Diagnóstica, Brasília, DF, Brazil.
6. Clínica Villas Boas, Brasília, DF, Brazil.

ABSTRACT

Objective: To evaluate the sagittal tomographic reformatting of the sternum using unpublished radiographic parameters (indexes and angles), comparing them between the different types of pectus, and controls. Methods: 44 patients with pectus deformities and controls underwent chest CT for analysis. The types of pectus were classified into: inferior *pectus carinatum* (IPC), superior (SPC) and lateral (LPC), and broad (BPE) and localized *pectus excavatum* (LPE). The following tomographic parameters were created and measured: (1) spine-manubrium-sternum index (SMS); (2) column-sternum index (CSI); (3) manubrium-sternal angle (MSA); (4) inferior manubrium angle (IMA); and (5) inferior sternum angle (ISA). Statistical analysis was performed between the pectus and control groups, and between the different types of pectus. Results: There was a significant difference between: a) *pectus excavatum* and *pectus carinatum* when analyzing the SMS, CSI, MSA and ISA indexes. b) LPE and control group for SMS and ISA. c) LPC and LPE, and LPC and BPE for SMS; d) BPE and LPC for CSI; e) IPC and LPE, and IPC and BPE for ISA; f) SPC and LPE, and SPC and BPE for IMA. Conclusion: The radiographic indexes and angles created provided differentiation parameters between patients with different types of pectus, and between these and controls. ***Level of Evidence II, Prognostic Studies.***

Keywords: *Pectus Carinatum*. Funnel Chest. Costal Cartilage. Sternum. Thoracic Wall. Tomography, X-Ray Computed.

RESUMO

Objetivos: Avaliar a reformatação tomográfica sagital do esterno por meio de parâmetros radiográficos inéditos (índices e ângulos), comparando-os entre os diferentes tipos de pectus e controles. Métodos: 44 pacientes com deformidades pectus e controles foram submetidos à TC do tórax para análise. Os tipos de pectus foram classificados em: pectus carinatum inferior (PCI), superior (PCS) e lateral (PCL), e pectus excavatum amplo (PEA) e localizado (PEL). Foram criados e mensurados os seguintes parâmetros tomográficos: (1) índice coluna-manúbrio-esterno (CME); (2) índice coluna-esterno (CE); (3) ângulo manúbrio-esternal (AME); (4) ângulo inferior do manúbrio (AIM); e (5) ângulo inferior do esterno (AIE). Foi realizada análise estatística entre os grupos pectus e controle, e entre os diferentes tipos de pectus. Resultados: Houve diferença significativa entre: a) pectus excavatum e pectus carinatum quando analisados os índices CME, CE, AIM e AIE; b) PEL e grupo controle para CME e AIE; c) PCL e PEL, e PCL e PEA para o CME; d) PEA e PCL para CE; e) PCI e PEL, e PCI e PEA para AIE; f) PCS e PEL, e PCS e PEA para AIM. Conclusões: Os índices e ângulos radiográficos criados forneceram parâmetros de diferenciação entre pacientes com diferentes tipos de pectus, e entre estes e controles. ***Nível de Evidência II, Estudos Prognósticos.***

Descritores: *Pectus Carinatum. Tórax em Funil. Cartilagem Costal. Esterno. Parede Torácica. Tomografia Computadorizada por Raios X.*

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INTRODUCTION

The anterior wall of the chest is well studied in images obtained from the coronal and axial planes,[1,2] and the Haller index is the best known method to evaluate the severity of *pectus excavatum* (PE).[2] Additionally, the axial tomographic slice is useful for the diagnosis of defects of the inferior third of the sternum, as occurs in the presence of sternal foramen[3] and sternal midline defects.[4] Few authors have analyzed the sternal region in cases of anterior deformity of the thorax through imaging exams in the sagittal plane, and little is known about its usefulness in classifying and

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The study was conducted at Centro Clínico Orthopectus.
Correspondence: Davi de Podestá Haje. SMHN – Q. 2 Bl. A, Edifício de Clínicas, sala 804, Brasília, DF, Brazil, 70710904. davihaje@yahoo.com.br

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evaluating its severity, and differentiating *pectus* from normal individuals. Welch,[5] in 1958, created a severity grading index for PE and differentiation from the normal ones, calculating the quotient between the sagittal diameter of the anterior portion of the vertebral body (level of the 9th thoracic vertebra) to the posterior plate of the sternum at the point of greatest deformity, and the sagittal diameter started at the end of the spine process of the third thoracic vertebra going to the anterior plate of the sternum. Derveaux et al.,[6] using plain chest radiographs evaluated according to the profile incidence in patients with PE and controls, developed an index that was proposed between the ratio of the sagittal diameter of the anterior portion of the vertebral body to the sternal manubrium region, and the sagittal diameter of the anterior portion of the vertebral body to the posterior plate in the distal third of the sternum, and showed that corrective surgery could improve this index. Haje et al.[7] concluded that some patterns of sternal curvature in the sagittal plane are more frequent in some types of *pectus* and controls, and developed indices that reflect the relative length of the various segments of the sternum.[8] From this analysis, the authors concluded that changes in sternal development, with early fusion of sternal growth plates, seem to have an influence on the etiology of the superior *Pectus Carinatum* (PC) and a lesser influence on other types of *pectus*.[8]
The complete interpretation of tomographic sections in sagittal reformatting of the sternal manubrium region of patients with *pectus* and normal individuals may require multiple parameter analysis. Some doubts may arise, such as: 1) what should be the position of the sternum and its inclination in relation to the spine?; and 2) are there varied angles of the manubrium, sternum, and between the manubrial and sternal regions?
The objective of this study was to evaluate the sagittal tomographic reformatting of the sternal region, creating imaging parameters with objective measurement that can characterize the different types of *pectus* and differentiate them from controls.

METHODS

A retrospective analysis of the medical records of 5,750 individuals with deformity in the anterior contour of the thorax (*pectus*) treated at our non-surgical *pectus* treatment center was performed from February 2004 to September 2014. From this sample, 181 patients with *pectus* who had undergone chest computed tomography were selected whose sternum and costal cartilages were to be studied. For the analysis of tomographic parameters, 44 patients were selected who had images as digitized media due to the need to use software (Osirix) for reconstruction and analysis. The exclusion criteria were: inadequate images (123 cases), previous surgery for resection of costal cartilage (three cases), iatrogenic *pectus* (one patient) and those with deformities associated with scoliosis greater than 10° (10 cases). See Figure 1.
The clinical diagnosis was defined by two evaluators who classified *pectus* according to the predominant type: *pectus carinatum* inferior (IPC), lateral (LPC) and superior (SPC), and localized (LPE) and broad *pectus excavatum* (BPE).[9-11]
Individuals with *pectus* and the control group (without *pectus*) were subdivided for analysis as shown in Table 1. The patients in the control group underwent chest CT for other reasons and were not known to have *pectus* or spinal deformities, being randomly selected from the imaging database of the radiology clinics involved in this study.
The *pectus* groups were composed of 44 patients (29 males and 15 females), 25 patients with PC (mean age = 14.3 years; SD = 8.86) and 19 with PE (mean age = 16.5; SD = 11.5). The control group consisted of 27 patients (14 males and 13 females), with a mean age of 17.4 years (SD = 15.9, SD = 9.5).

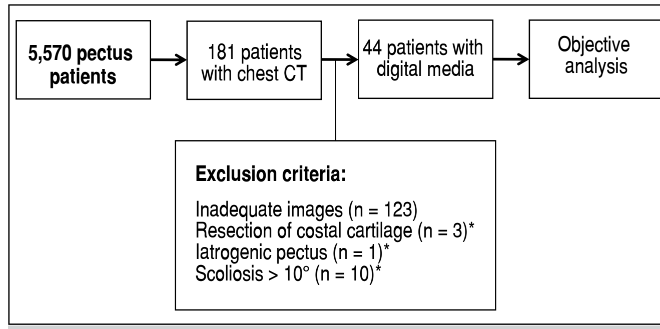


Figure 1. Method for selecting the patient sample.

Images were selected in the Digital Imaging and Communications in Medicine (DICOM®) format, with reconstruction and analysis made via OsiriX v. 5.8.2 32-Bit (Geneva, Switzerland). The images in the sagittal plane were standardized using the 3D evaluation software MIP to amplify the slices, since the sternum of these patients may present significant variations in the coronal and sagittal planes. For analysis, slices made as close as possible to the median plane of the sternum were considered.
The parameters illustrated in Figure 2 were used for the analysis of the *pectus* and control groups.

Statistical analysis

For statistical analysis, we performed the comparison: 1) between the group of patients with PE and CP; 2) between each type of *pectus* and the control group; and 3) between the different types of *pectus*. In the statistical analysis, the software package SPSS version 15.0 was used. To compare the tomographic parameters between all groups we used Pearson's chi-square test (cross-tabulation). One-way analysis of variance (ANOVA) was used for independent groups for the difference between the means of the radiographic parameters studied between the groups. A p-value less than or equal to 0.05 was considered statistically significant.
An informed consent form previously approved by the Ethics and Research Committee of our institutions (42165414.5.0000.5553) was signed by the patient or their legal guardian.

RESULTS

Table 2 shows the results of tomographic parameters found in pectus patients and controls.
The following statistically significant results were found:
1. Comparison between the group of patients with PC, PE and controls:
- SMS: it was higher in the controls compared to the PE (mean 1.94 > 1.67, p = 0.00), and higher in PC individuals compared to the PE (mean 2.05 > 1.67, p = 0.006). Of the controls, 18 (66.7%) patients had SMS > 1.88. The SMS index above 1.88 significantly decreases the chance of the patient having PE (p = 0.00). Of the total number of patients with *pectus* (n = 44), among those who have a SMS index above 1.88 (n = 19), only 4.5% (n = 2) have PE, and no values greater than 2.26 were found for those with PE;

Table 1. Subdivision into groups of patients with *pectus* and control group for analysis.

	***Pectus* groups (n = 44)**					**Control group**
	pectus carinatum (n = 25)			*pectus excavatum* (n = 19)		
Objective analysis	IPC (n = 11)	LPC (n = 4)	SPC (n = 10)	LPE (n = 15)	BPE (n = 4)	Control (n = 27)

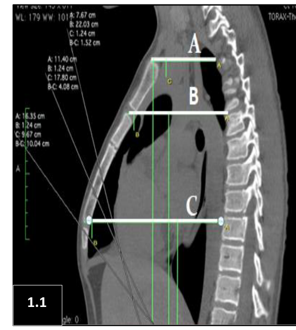
IPC: inferior *pectus carinatum*; LPC: lateral *pectus carinatum*; SPC: superior *pectus carinatum*; LPE: localized *pectus excavatum*; BPE: broad *pectus excavatum*.

→ Spine-manubrium-sternum index (SMS)

→ C/A: division of the distance between the antero-inferior end of the sternum and the thoracic vertebra of the same level (C) by the distance between the anterosuperior end of the manubrium and the thoracic vertebra of the same level (A).

→ Spine-sternum index (CSI)

→ C/B: division of the distance between the anteroinferior end of the sternum and the thoracic vertebra of the same level (C) by the distance between the anterosuperior end of the sternum and the thoracic vertebra of the same level (B).



→Sternal Manubrium Angle (MSA)

→ formed between the lines passing through the anterior ends of the manubrium and the body of the sternum. In the case of curved sterna, the line starts at the sternal proximal pole in the anterior region of the sternal plate and ends at its distal end, in the anterior region of the sternal plate.

→ Inferior Manubrium Angle (IMA)

→ angle between the line drawn between the inferior pole of the manubrial body with the corresponding thoracic vertebra and the line drawn by the anterior axis of the manubrium.

→ Inferior Sternum Angle (ISA)

→ angle between the line drawn between the inferior pole of the sternal body with the corresponding thoracic vertebra and the line drawn by the anterior sternal axis on the profile.

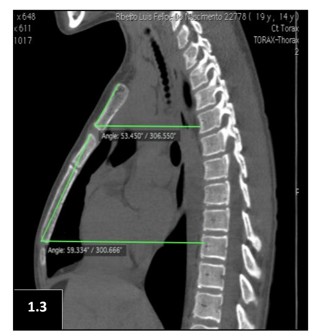


Figure 2. Indices and angles used in the objective analysis.

Table 2. Results of tomographic parameters found in those with *pectus* and in the control group.

		TOMOGRAPHIC PARAMETERS (mean; SD; min-max)				
		SMS	**CSI**	**IMA***	**ISA***	**MSA***
PECTUS	***PECTUS CARINATUM***	2.05; 0.37; 1.39-3.02	1.27; 0.15; 1.01-1.56	58.02; 8.77; 38.63-74.22	73.96; 9.53; 59.33-90.27	18.93; 6.96; 7.6-30.50
	IPC	2.06; 0.32; 1.59-2.60	1.29; 0.15; 1.1-1.53	59.26; 8.81; 43.61-71.62	72.5; 10.78; 59.33-87.48	16.77; 7.6; 3.29-34.28
	LPC	2.35; 0.58; 1.65-3.02	1.36; 0.17; 1.17-1.56	62.72; 10.48; 50.06-74.22	71.72; 8.85; 60.50-81.98	15.21; 5.48; 7.97-19.93
	SPC	1.93; 0.31; 1.39-2.43	1.21; 0.14; 1.01-1.44	54.78, 7.69; 38.63-66.05	76.46; 8.66; 59.83-90.27	22.8; 5.13; 16.30-30.50
	PECTUS EXCAVATUM	1.67; 0.21; 1.33-2.26	1.13; 0.18; 0.84-1.76	67.10; 5.73, 55.33-81.31	84.58; 7.94, 75.92-102.5	19.46; 5.94; 11.81-31.44
	LPE	1.68; 0.22; 1.33-2.26	1.16; 0.19; 0.94-1.76	66.42; 4.94; 55.33-76.67	84.05; 6.56; 76.0-97.62	19.34; 5.3; 11.81-30.81
	BPE	1.59; 0.15; 1.37-1.70	1.05; 0.15; 0.84-1.17	70.17; 7.68; 64.02-81.31	87.71; 12.1; 75.92-102.5	20.78; 8.6; 13.17-31.44
CONTROL		1.94; 0.23; 1.51-2.36	1.24; 0.11; 1.01-1.43	60.10; 7.06; 40-72.18	76.61; 5.75; 62.63-87.58	18.66; 4.94; 10.3-24.5

*units in degrees. SMS: spine-manubrium-sternum index; CSI: column-sternum index; IMA: inferior manubrium angle; ISA: inferior sternum angle; MSA: manubrium-sternal angle; IPC: inferior *pectus carinatum*; LPC: lateral *pectus carinatum*; SPC: superior *pectus carinatum*; LPE: localized *pectus excavatum*; BPE: broad *pectus excavatum*.

- CSI: was higher in PC compared to PE (mean 1.27 > 1.13; p = 0.01). Only one patient (5.2%) of the 19 who have PE has CSI > 1.3. Of the patients with PC, 16% (n = 4) had a CSI index < 1.12 and, of those with PE, 47.7% (n = 9), whereas values lower than 1.01 were seen only in those with PE;
- IMA: there was a difference in the comparison between the PE and PC, and between PE and control, with no significant difference between PC and control. Of the patients with an aim angle below 61.47°, only 5.5% (n = 1) had PE;
- ISA: there was a difference between PE and PC, and between PE and control (p = 0.00), but no significant difference (although there is a trend) between control and PC, with higher values for patients with PE. No PE has EIE < 75.9°, which occurred in controls and in PC individuals;
- MSA: there was no significant difference between those with PE, PC and control.

Examples of the radiographic parameters evaluated in case of PE and PC are illustrated in Figure 3.

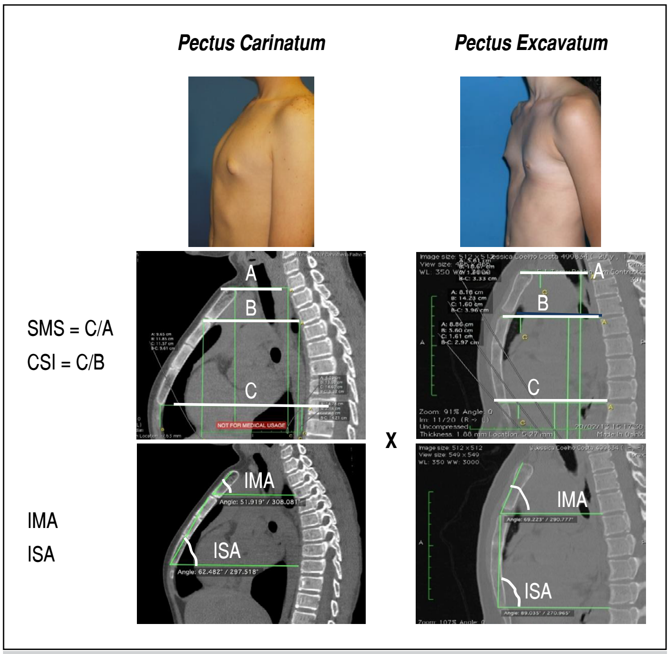


Figure 3. The mean values of the spine-manubrium-sternum index and the spine-sternum index were significantly higher in patients with *pectus carinatum* than in those with *pectus excavatum*, showing in the latter a greater approximation of the spine's inferior portion of the sternum in relation to the proximal pole of the sternum and manubrium. The mean inferior angles of the manubrium and inferior sternum were significantly higher in those with *pectus excavatum* compared to those with *pectus carinatum*, denoting a more verticalized manubrium and sternum or with an inferior extremity more tilted to the posterior in the former, respectively.

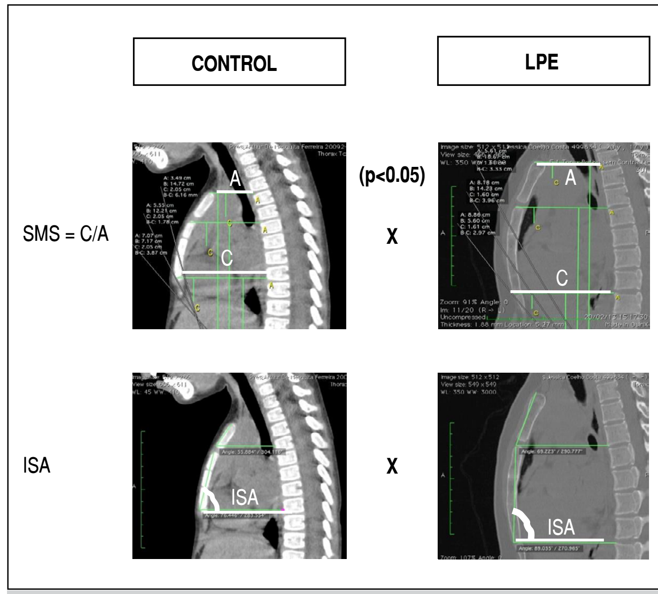


Figure 4. Illustration of measurement of indexes and angles performed. For the analysis of each radiographic parameter separately, between *pectus* groups and controls, there was a significant difference in the spine-manubrium-sternum index and in the inferior angle of the sternum (localized *pectus excavatum* × control). The mean values of the spine-manubrium-sternum index were significantly higher in the controls than in the individuals with *pectus excavatum*, showing that in the latter a greater approximation of the spine's inferior portion of the sternum in relation to the proximal pole of the manubrium. The mean inferior angles of the sternum were significantly higher in those with *pectus excavatum* compared to the controls, denoting a more vertical sternum or with its inferior portion more tilted towards the posterior in the former.

2. Comparison between the different subtypes of *pectus*, and between these and control, with statistical significance being observed in the following comparisons:

- SMS: LPE and control (p = 0.05); between LPE and IPC (p = 0.00); LPC and LPE (p = 0.00); LPC and BPE (p = 0.00); e) still with a tendency to significance between BPE and IPC. See example in Figure 4.
- CSI: between BPE and LPC (p = 0.00).
- IMA: between PC and LPE cases (p = 0.003), and between SPC and BPE (p = 0.008). In the SPC individuals, there is a smaller IMA angle compared to PE cases. See Figure 5.
- ISA: between the control group and LPE (p = 0.04); SPC and LPE; IPC and LPE (p = 0.00); IPC and BPE (p = 0.01). See example in Figure 4.
- MSA: No significant difference between groups, but with a tendency for SPC (mean = 22.8) to present higher values and IPC (mean = 16.77) to present lower values.

DISCUSSION

The present study contributed by adding some radiographic parameters that can be added in imaging reports that study the chest of patients with and without *pectus*, helping to understand the positioning of the manubrial and sternal bones in the sagittal plane, in addition to the relationship of these bones with the spine. The analysis of the SMS suggests that the PE presents the inferior end of the sternum relatively closer to the spine than controls and PC cases, while in patients with PC the inferior end of the sternum is no further away from the spine compared to control. Derveaux et al.[6] created an index similar to SMS, but it differs because it was performed using radiographs, making

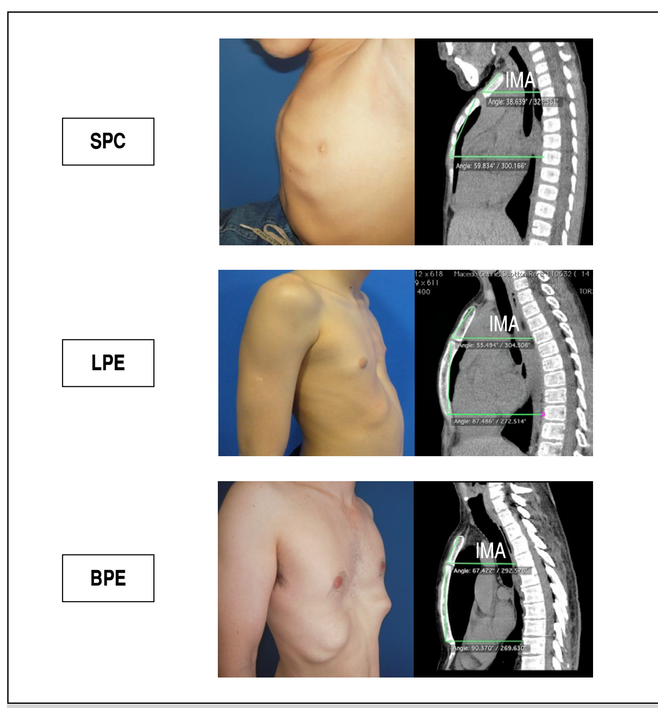


Figure 5. Illustration of measurement of indexes and angles performed. The mean values of the inferior angle of the manubrium were significantly inferior in the cases of *pectus carinatum* superior compared to the cases of *pectus excavatum*, with the latter showing a more verticalized manubrium compared to the former.

the measurement method more inaccurate than in CT, besides the possibility of magnification and positioning errors (mainly sternal rotation or chest rotation of the patient), and not having used measurement software, which achieves more precision and allows to better determine the median region of the sternum in relation to radiography. In addition, Derveaux et al.[6] traced the inferior line of their parallel index in relation to the vertebral body directed to the xiphoid, making it inclined in relation to the upper line of this index. In the SMS, the lower line was drawn towards the thoracic vertebra of the same level. Therefore, comparing the SMS with the configuration index created by Derveaux et al.[6] is not ideal, although it is also able to demonstrate greater or lesser distance from the lower extremity of the sternum relative to the spine and has also found a difference between the control group and PE, and between PC and PE, but also found a significant difference between PC and controls, differing in this aspect of our study.

This deviation from the longitudinal axis of the sternum to the posterior axis in patients with *PE*, demonstrated by the SMS and CSI, may be related to the etiopathogenesis of the deformity. Francis et al.[12] argues that the sternum is the key factor causing *pectus*, with its distal extremity being more depressed in the case of PE, and the opposite in the case of PC. Our previous study of the analysis of sternal curvature patterns concluded that this does not always occur, and there are cases of PE in which the lower extremity of the sternum has an anterior tilt.[7]

We found that if the SMS > 1.88 and/or CSI > 1.3 and/or IMA $< 61.37°$ and/or ISA $< 76°$, there is a low probability of the patient under analysis having PE, but there are no cutoff values that allow to differentiate if the patient has PC or are controls. The CSI index was higher than 1.3 in only one patient with PE, and the SMS was significantly lower in the LPE than in the control group.

The ISA angle was significantly higher in the LPE compared to the controls and to the IPC group. The IMA and ISA indexes showed that in the comparison between the SPC and PE cases, there is a smaller angle IMA and ISA of the SPC compared to the cases of PE, suggesting a more vertical manubrium or with greater aim in the latter compared to the former, making this angle a possible tool in the imaging differentiation of these deformities. The IMA angle was significantly greater in patients with PE compared to controls and CP.

The fact that MSA did not show a significant difference between the subtypes of *pectus* suggests that the etiopathogenesis of deformity is not related to this angulation. Perhaps future studies evaluating this angle in cases of more severe SPC than the present study will reach a more significant conclusion regarding this angulation. Joshua et al.[13] analyzed an angle called sternal manubrium, but it was measured with a different methodology, representing the angle between the manubrium and the proximal third of the sternum in normal individuals and found no difference between the individuals pre- and post-puberty.

In the present study, *pectus* patients without scanned tomographic images were excluded, which left the number of patients analyzed with fewer cases than ideal for some analyses, especially for the group of patients with BPE and LPC. One bias is that the parameters analyzed are subject to variations in interpretation and measurement, respectively, intra- and inter-examiners, requiring further studies to verify the reliability of the method utilized.

Although we used a control group, another possible bias of the present study is that we do not know if the CT parameters studied may vary with age and gender in normal and control subjects. Derveaux et al.[6] found variations in the index according to age. Before analysis, it was important to find the median line of the sternum, which is not necessarily the median line of the body. We also know that when we observe the sternum in the coronal plane, it can be inclined or oblique in the body, making it difficult to trace the median line.

We also know that the same clinical types of *pectus* are not necessarily the same, suggesting that there is a need to further improve clinical classifications. Haje, Haje and Silva Neto[11] recently subdivided the LPE and SPC classifications. The better definition of these clinical subtypes may help in the creation of tomographic parameters to differentiate them.

The Haller index is used before and after the correction surgery of the PE,[2] and it is possible to use it for the radiological parameters created, especially the CSI, SMS and ISA, because they reflect the degree of positioning of the portion of the lower extremity of the sternum, but more studies will be necessary to validate this hypothesis. During Nuss surgery to correct the PE, the body and the lower extremity of the sternum are elevated by the respective nails, and undercorrections or hypercorrections are not uncommon.[14] Derveaux et al.[6] found an improvement in their index after corrective surgeries for *pectus*.

Some of the radiographic parameters created in the present study may suggest whether the patient has PC or PE, and may be analyzed in conjunction with other parameters to be analyzed in coronal and axial reformatting, requiring a correlation between all these variables in future studies.

The main author has extensive experience in the treatment of *pectus* with the use of orthoses and exercises. Initially, in some situations, a CT scan focusing on the anterior aspect of the chest in order to better understand these deformities[1] before treatment, but this examination has been less and less performed because the tomographic patterns in the different types of deformity seemed to be repeated, and the clinical types and the examination did not modify the treatment, in addition to the concern with radiation. Eventually, we indicated CT to evaluate the prognosis of spontaneous worsening, especially in mild SPC during childhood (evaluating whether there is early fusion of the manubrium-sternal region or sternal shortening),[1,8,11] and in some cases of LPC, when there is an asymmetry of the pectoral region, serving to evaluate the degree of participation of bone deformity and soft tissues in the genesis of asymmetry.[11]

CONCLUSIONS

The radiographic indices and angles created (except for the angle between the manubrium and the sternum) provided differentiation parameters between patients with different types of *pectus*, and between these and controls.

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