Growth characterisation of intra-thoracic organs of children on CT Scans

François Coulongeat, Ms Jarrar, Lionel Thollon, Thierry Serre

▶ To cite this version:

François Coulongeat, Ms Jarrar, Lionel Thollon, Thierry Serre. Growth characterisation of intra-thoracic organs of children on CT Scans. Computer Methods in Biomechanics and Biomedical Engineering, 2013, 16 (2), pp217-221. 10.1080/10255842.2011.616943 . hal-00851157

HAL Id: hal-00851157

https://hal.science/hal-00851157

Submitted on 12 Aug 2013

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Growth characterization of intra-thoracic organs of children on CT Scans

François Coulongeat*, Mohamed-Salah Jarrar, Lionel Thollon, Thierry Serre

Aix-Marseille Université, IFSTTAR, Université de la Méditerranée-Aix-Marseille, LBA, F-13916 Marseille

*Corresponding author. E-mail: francois.coulongeat@ifsttar.fr

Growth characterization of intra-thoracic organs on CT Scans

This paper analyses the geometry of intra-thoracic organs from CT scans performed on 20 children aged from 4 months to 16 years. The aim is to find the most reliable measurements to characterize the growth of heart and lungs from CT data. Standard measurements available on chest radiographies are compared with original measurements only available on CT scans. These measurements should characterize growth of organs as well as changes in their position relative to the thorax. Measurements were considered as functions of age. Quadratic regression models were fitted to the data. Goodness of fit of the models was then evaluated. Positions of organs relative to thorax have a high variability compared with their changes with age. Heart and lung lengths and volumes as well as thorax diameter well fit the models of growth. It could be interesting to study these measurements with a larger sample size in order to define growth standards.

Keywords: 3D reconstruction, intra-thoracic organs, child, growth standards, lung, heart

Introduction

Anthropometric data are useful in the medical field, forensic medicine, design of products, anthropology as well as human modelling. Several studies have characterized external geometry of children ((Snyder et al. 1975), (Smith and Norris 2004), (Serre et al. 2006)). Fewer studies focused on anthropometry of paediatric inner organs.

The present paper is focused on the heart and lung growth. Some studies are based on post-mortem data. (Thurlbeck 1982) and (Zeltner et al. 1987) measured post-mortem volume of children's lungs by weighing the inflated lungs in water and in air. However, due to ethical issues, this kind of data is rare concerning children. Moreover, dimensions of the heart and lungs are constantly changing in vivo due to cardiac cycle and respiration. Consequently, several unknowns remain about reliability of post-mortem dimensions. Other studies are based on medical imaging. (Simon et al. 1972) measured several dimensions of heart and lungs from chest radiographies of children aged from 5 to 19 years. (De Jong et al. 2003) and (Gollogly et al. 2004) performed 3D reconstructions and measurements of pulmonary system from CT scan of children. (De Jong, et al. 2003) showed that computed tomography scans can be used to estimate weight and volume of normal lungs during the growth period with a sample of 35 subjects aged from 15 days to 17.6 years. (Gollogly, et al. 2004) give normal value of lung volume based on more than 1000 CT scans of children and young adults.

While radiography only allows two dimensional measurements, Computed Tomography (CT) allows three dimensional measurements. Moreover, since CT provides in vivo data, it can be used to monitor thoracic growth. (Schlesinger et al. 1995) reported that accuracy of this method is better than the estimate from chest radiography compared to results of pulmonary capacity from plethysmography. Furthermore, (Coulongeat et al. 2011) showed that there is a very low systematic intra- and inter-observer bias in measurements from CT scans. Thus, CT seems to be very suitable for studying geometry of inner organs. However, to the knowledge of the authors, no research described heart growth from CT scans data.

The aim of this study is to find the most reliable measurements to characterize heart and lung growth from CT data. Standard measurements available on chest radiographies will be compared with original measurements only available on CT scans. These measurements should characterize organs growth as well as changes in their position relative to the thorax. They should be dependent of age and have a relatively low variability. Some characteristic measurements will also be studied in further detail.

Material and methods

Sample

Thoracic CT scans were performed at the University Hospital Centre of Nice and

Marseille's Hospitals (France) between 2008 and 2009. They were performed to a medical diagnosis purpose on 31 children and young adults aged from 4 months to 23 years and next were used for research with approval of hospitals. All subjects with a pathology which could influence the results were excluded from the study. The frequency distribution of CT data as function of age is displayed in Figure 1.

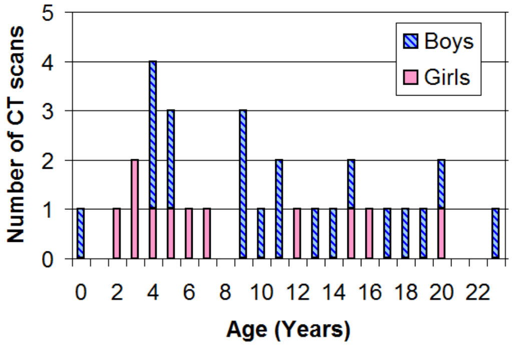

Figure 1

Histogram of the frequency distribution of CT data as a function of age**.**

The examinations were performed on a Siemens Sensation 64 scanner, on a GE LightSpeed VCT scanner or on a GE LightSpeed Pro 16. CT data were not correlated with an electrocardiogram (ECG) which would allow to correlate the CT data with their corresponding phases of cardiac contraction. The images were archived in DICOM (Digital Imaging and Communications in Medicine) format. Beam current and potential ranged 20–270 mA and 80–140 kV. Pixel size and slice increment ranged 0.38-087 mm and 0.5-5 mm.

Modelling

CT scans were performed in supine position at full-suspended inspiration from age of 6 years and during full-forced inspiration under general anaesthesia for younger children. Data were analysed using Mimics© Medical Imaging Software (Materialise Software, Brussels, Belgium). The parameters used for calculating 3D models are as follow: no matrices reduction, no triangles reduction, no shells reduction, no smoothing and a contour interpolation method.

A segmentation of images based on histogram methods was used in order to define boundaries of the organs. A visual control was performed slice to slice. Observer had then to improve manually selected area boundaries. Observer had to pay a particular attention to the top and the base of the heart. Main bronchus under the carina was considered as a part of the corresponding lung but pulmonary vessels were not considered to belong to the lungs. Heart boundaries were defined as the pericardium while the heart was at rest during diastole. Volumes were measured from the 3D models.

Measurements

Four specific points were located on the lungs. The apexes of the right and the left lungs defined as the upper points of the lungs were named Ar and Al, respectively. The bases of the right and the left lungs defined as the most lateral points of the cul-de-sac were named Br and Bl, respectively. Two specific points were located on the heart. The top of the heart defined as the centre of the ascending aorta in the same transversal level as the carina was named Ht. The second point defined as the apex of the heart was named Ha. We defined specific measurements from these points and the 3D models (Figure 2):

(1) the length of the right lung is defined as the 3D distance between Ar and Br as well as the left lung between Al and Bl.

(2) the gap between lungs apexes is defined as the 3D distance between Ar and Al

(3) the gap between bases is defined as the 3D distance between Br and Bl.

(4) the heart length is defined as the 3D distance between Ht and Ha.

(5) the heart and lung volumes are calculated from 3D reconstructions.

(6) the transverse diameter of thorax is defined as the sum of the furthest projections of the right and the left lungs to the midline.

(7) the transverse diameter of the heart is defined as the sum of the furthest projections of the heart to the right and the left of the midline.

(8) the cardiothoracic ratio is defined as the ratio of the transverse heart diameter to the transverse thorax diameter (Danzer 1919).

(9) the position of Br, Bl, Ht and Ha relative to the vertebral column is defined specifying the vertebra which is in the same transverse plane. Vertebrae were numbered from 1 corresponding to T1 to 13 corresponding to L1. Height of each vertebra was divided into 4 numbered parts:

- 0.00 corresponding to the upper intervertebral disc,
- 0.25 corresponding to the top of the vertebra,
- 0.50 corresponding to the middle of the vertebra,
- 0.75 corresponding to the base of the vertebra.

The location of the transverse plane is obtained by adding the number of the vertebra and the number of the part. For instance, the top of T7 corresponds to 7.25 and the intervertebral disk between T4 and T5 corresponds to 5.0. The relative location of Br, Bl, Ht and Ha was defined by an operator thanks to a 3D model of the vertebral column.

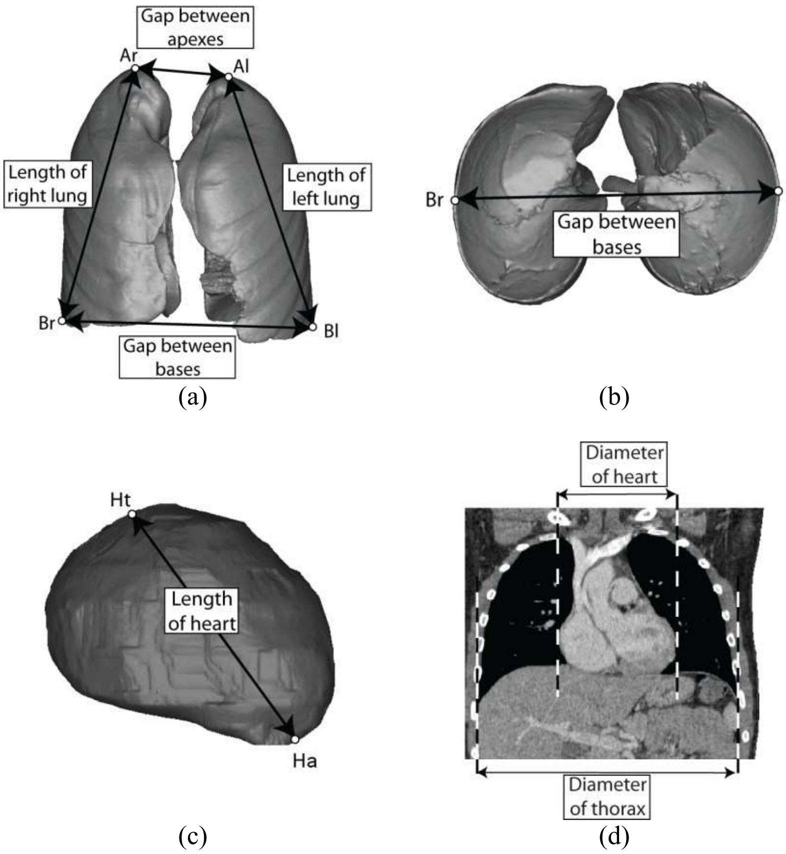

Figure 2
Specific points and measurements of thorax: front (a) and transverse (b) views of lungs, front view of heart (c) and front view of thorax (d)

Statistical analysis

Measurements were considered as functions of age. Quadratic regression models were fitted to the data using Microsoft Office Excel (Microsoft, Redmond, USA). Form of the regression models is given by:

$$Y = \alpha_0 + \alpha_1 X + \alpha_2 X^2 \tag{1}$$

where Y is the measurement, X is the age and α_i are the coefficients of regression. The goodness of fit of the models was evaluated with the respective coefficients of determination R^2.

Results

Table 1 displays coefficients of regression models of measurements as functions of age and respective coefficients of determination.

Table 1. Coefficients of regression models of measurements and respective coefficients of determination R^2.

	Measurements (*units*)	α_0	α_1	α_2	R^2
Lungs	Volume-right (cm^3)	-7.58	95.88	1.52	0.86
	Volume-left (cm^3)	-2.54	72.33	2.35	0.83
	Volume-both (cm^3)	-10.12	168.21	3.77	0.85
	Length-right (*cm*)	80.87	14.28	-0.26	0.85
	Length-left (*cm*)	95.15	11.78	-0.15	0.87
	Gap between apexes (*cm*)	45.71	2.70	-0.05	0.77
	Gap between bases (*cm*)	140.64	7.25	-0.02	0.90
	Diameter of thorax (*cm*)	140.42	7.63	-0.03	0.90
	Position of the right base	9.78	0.24	-0.01	0.25
	Position of the left base	10.71	0.11	0.00	0.15
Heart	Volume (cm^3)	122.62	22.77	0.40	0.82
	Length (*cm*)	70.53	6.20	-0.11	0.82
	Diameter (*cm*)	74.35	3.39	-0.05	0.56
	Position of the top	5.17	0.02	0.00	0.07
	Position of the base	10.49	0.09	0.00	0.04
	Cardio-thoracic ratio	0.525	-0.003	0.000	0.23

The position of organs relative to vertebral column is not dependent of age considering the low value of α_1, α_2 as well as the respective coefficients of determination. It can be seen in Figure 3 which gives the measured positions of the heart relative to the vertebral column as well as the respective regression models.

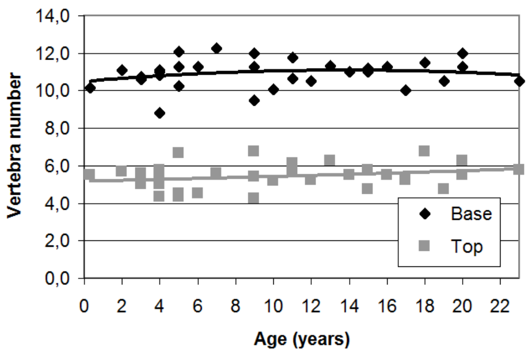

Figure 3
Position of the heart relative to the vertebral column. Lines represent quadratic regression models.

The cardiothoracic ratio decreases with age but the goodness of fit of the model is very low considering the coefficient of determination. It can be seen in Figure 4 which gives the measured cardiothoracic ratio as well as the respective regression model. The increase of heart diameter is stronger but the goodness of fit of the model is low considering the coefficient of determination.

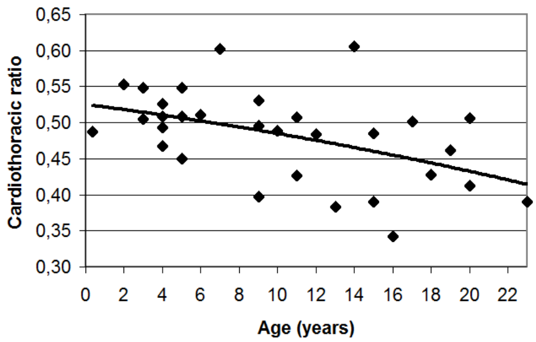

Figure 4
Cardiothoracic ratio. Line represents the quadratic regression model.

Other measurements well fit the quadratic models considering their respective coefficients of determination. Figure 5 shows lung volume. Growths of both lungs are almost equivalent. But the volume of the right lung is consistently higher than the volume of the left lung. The gap between the bases of lungs and the diameter of thorax are as well almost equivalent. The maximum difference between these measurements is indeed of 4% with a mean of 1%.

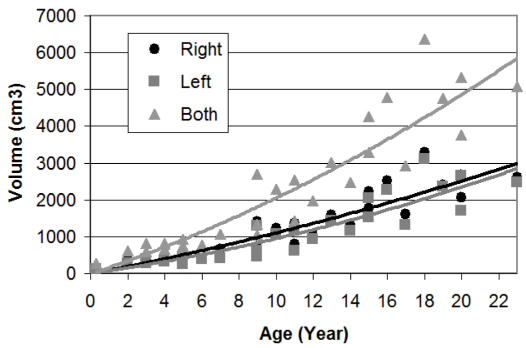

Figure 5
Lung volume. Lines represent quadratic regression models.

Discussion

CT data were provided by several types of CT scan due to their several origins. Furthermore, voltage, dose, pixel size and slice increment are different due to the large range of ages and purpose of scanning. However (Coulongeat, et al. 2011) showed that it has not a significant influence on the relative deviation of measurements. They also showed the good inter- and intra- observer reproducibility of measurements on heart and lungs from CT data.

The results point out the differences of reliability between measurements to characterize thorax growth. For instance, it is hard to observe changes of position of intra-thoracic organs relative to the vertebral column regarding the variability of the results. Changes with age are indeed negligible compared with the variability.

Heart transverse diameter increases with age but the variability is too high to deduce a reliable model of growth. This variability could be due to the difference of type of shape between subjects as described by (Lincoln and Spillman 1928). The description of the several shapes is based on 2D radiographies. It explains that transverse diameter, is strongly influenced by the type of shape, by definition. Several heart shapes have also been detected in the present study. However measurements of volume and length of the heart (measured in 3D) seems less affected by the differences of shape. Data of the volume and the length fit indeed the regression models of growth despite that the CT data were not correlated with an electrocardiogram which would allow to isolate phases of cardiac contraction.

Cardiothoracic ratio seems decrease with age in accordance with (Maresh 1970) but the goodness of fit of the model is very low. By definition, cardiothoracic ratio is a function of the heart transverse diameter. This ratio is then dependent on the type of heart shape which could explain the high variability of measurements. Consequently, if the cardiothoracic ratio can be used to detect some pathologies of heart size based on medical thresholds, it seems difficult to deduce a reliable model of growth.

Contrary to heart growth, several studies considered lung growth based on CT scans. Volumes measured on the present study are consistent to the model of growth given by (De Jong, et al. 2003) and (Gollogly, et al. 2004). However these studies are focused on the volume or the weight. The present study shows that lung length, thorax diameter and gaps between the bases and between the apexes of the lungs also give reliable models of growth. Thorax diameter seems as relevant as lung volume to describe the growth of the lungs. However, (Coulongeat, et al. 2011) showed that the measure of the thorax diameter is less intra- and inter- observer dependent than the measure of the volume. Furthermore the measure of the thorax diameter is quicker than the measure of the lungs which requires a 3D reconstruction. Thus, if the lung volume can give additional information on potential pathologies, thorax diameter seems to be as relevant and easier to measure for describing normal growth of lungs.

Considering the limited number of CT scans, sex differences were not studied. Furthermore, regression models could be refined with a larger sample size.

Conclusion

The present study compared several measurements in order to find the most reliable to characterize heart and lung growth as well as changes in their position relative to the thorax. Some of laws of growth are also suggested for these measurements. However, these laws need obviously to be validated and improved by studies with a higher number of subjects.

Several studies already characterized the growth of lung. However, to compare a subject to the normal growth, we recommend studying thorax diameter which is easier and quicker to measure even if lung volume can provide additional information.

To the knowledge of the authors, no other study described in vivo the growth of heart volume and length from direct measurements. And yet, volume and length seem to be the most reliable measurements to characterize the growth of the heart. It could be interesting to study these measurements with a larger sample size in order to define growth standards.

Acknowledgments

This study was partly funded by the French National Research Agency (ANR) in the framework of the “SECUR_ENFANT” project. This project was also supported and partly funded by the "French institute of science and technology for transport, development and networks" (IFSTTAR) and by the Provence-Alpes-Côte d'Azur French region. The authors would like to thank Dr. Chaumoitre of the Department of Radiology at the North Hospital of Marseille (France) as well Dr. Breaud of the University Hospital Centre of Nice (France) for their assistance.

References

Coulongeat F, Jarrar M-S, Serre T, Thollon L. 2011. Reproducibility of geometrical acquisition of intra-thoracic organs of children on CT scans. Comput Method Biomec. (in press).

Danzer C. 1919. The cardiothoracic ratio: an index of cardiac enlargement. Am J Med Sci. 157(4):513.

De Jong PA, Nakano Y, Lequin MH, Merkus PJ, Tiddens HA, Hogg JC, Coxson HO. 2003. Estimation of lung growth using computed tomography. Eur Respir J. 22(2):235-238.

Gollogly S, Smith JT, White SK, Firth S, White K. 2004. The Volume of Lung Parenchyma as a Function of Age: A Review of 1050 Normal CT Scans of the Chest With Three-Dimensional Volumetric Reconstruction of the Pulmonary System. Spine. 29(18):2061-2066.

Lincoln E, Spillman R. 1928. Studies on the hearts of normal children : II. Roentgen-Ray Studies. Am J Dis Child. 35(5):791-810.

Maresh M. 1970. Measurements from roentgenograms, heart size, long bone lengths, bone, muscles and fat widths, skeletal maturation. In: Human Growth and Development Springfield: Charles C. Thomas. p. 155-200.

Schlesinger A, White D, Mallory G, Hildeboldt C, Huddleston C. 1995. Estimation of total lung capacity from chest radiography and chest CT in children: comparison with body plethysmography. Am J Roentgenol. 165(1):151-154.

Serre T, Lalys L, Brunet C, Bartoli C, Christia-Lotter A. 2006. 3 and 6 Years Old Child Anthropometry and Comparison with Crash Dummies. SAE Technical Paper. 2006-01-2354.

Simon G, Reid L, Tanner JM, Goldstein H, Benjamin B. 1972. Growth of radiologically determined heart diameter, lung width, and lung length from 5-19 years, with standards for clinical use. Arch Dis Child. 47(253):373-381.

Smith SA, Norris BJ. 2004. Changes in the body size of UK and US children over the past three decades. Ergonomics. 47(11):1195-1207.

Snyder RG, Spencer ML, Owings CL, Schneider LW. 1975. Physical Characteristics of Children as Related to Death and Injury for Consumer Product Design and Use. Highway Safety Research Institute, Ann Harbor.

Thurlbeck WM. 1982. Postnatal human lung growth. Thorax. 37(8):564-571.

Zeltner TB, Caduff JH, Gehr P, Pfenninger J, Burri PH. 1987. The postnatal development and growth of the human lung. I. Morphometry. Respir Physiol. 67(3):247-267.