0021-7557/08/84-05/410
Jornal de Pediatria

ORIGINAL ARTICLE

Chest diameter ratios for detecting static hyperinflation in children using photogrammetry

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Abstract

Objectives: To develop a photogrammetric method capable of identifying increases in anteroposterior chest diameters suggestive of pulmonary hyperinflation, and to test it with both asthmatic and asthma-free children.

Methods: Two distinct study designs were used to achieve these two objectives. The first was a descriptive analysis of diameters measured at the height of the axilla and of the xiphoid on digital images of 56 children aged 8 to 12 years photographed in the orthostatic position. The second was a case-control study of (a) 19 asthmatic children in treatment for at least 12 months; and (b) 37 children free from asthma with no prior history of complaints of respiratory/allergic disease. Diameters were measured on images of the front and left side views using CorelDRAW®, and the ratio between the front and side diameters was calculated for the axillary and xiphoid measurements, providing the diameter ratios. Diameter ratios close to or greater than 1 represent geometry tending towards a cylindrical shape, typical of hyperinflation on radiographs.

Results: Analysis with the *t* test for independent samples revealed a mean diameter ratio at the sternum that was significantly greater in the group of asthmatic children ($p < 0.01$) than the mean for the whole sample and also than the mean for the children without asthma.

Conclusions: Despite the existence of disagreement on the best instruments, methods and times for identifying hyperinflation, results indicate that a system using diameter ratios obtained by photogrammetry is a promising tool for the identification of a kinesiopathological manifestation that is known to determine air entrapment in asthma patients. Research that combines clinical data with longitudinal intrapatient follow-up will be necessary to establish the strength of the evidence found in this study.

J Pediatr (Rio J). 2008;84(5):410-415: Hyperinflation, photogrammetry asthma.

Introduction

Pulmonary hyperinflation is the result of an imbalance between the static forces that determine relaxation volume (Vrelax) and/or the dynamic components, including respiratory pattern, airway resistance and postinspiratory activity of inspiratory muscles. To a radiologist, hyperinflation translates as increased total lung capacity (TLC) visible on X-rays taken after maximum inspiration. In the clinical context, it is manifest as an abnormal increase in lung volume at the end of a spontaneous expiration, i.e. an abnormal increase in functional residual capacity (FRC).[1,2]

In a number of types of lung disease, hyperinflation is one clinical sign that can be detected by physical examination,[2] and it is necessary to establish the pathophysiologic mechanism causing the air to be trapped in the lungs before proposing definitions or interventions.[3] Hoppin Jr. stated that, "the lung and chest wall are wedded for life, for better or worse, in

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No conflicts of interest declared concerning the publication of this article.

Suggested citation: Ricieri DV, Rosário NA, Costa JR. Chest diameter ratios for detecting static hyperinflation in children using photogrammetry. J Pediatr (Rio J). 2008;84(5):410-415.

Manuscript received Dec 12 2007, accepted for publication Jun 10 2008.

doi:10.2223/JPED.1822

sickness or in health,"[4] and considers pulmonary and thoracoabdominal functions to be volume dependent, since the majority of ventilatory performance parameters reflect this "marriage." One example is the parameter forced expiratory volume in 1 second (VEF_1), the value of which is reduced by limited pulmonary expiratory capacity or by the inspiratory capacity of the chest wall.[4]

Biomechanical parameters have been established over decades of study of respiratory movements.[5-8] Specifically with relation to asthma, the important fact is that obstruction of both central and peripheral airways and the remodeling that accompanies inflammation lead to chronic hyperinflation and exacerbate the disease.[9] Chronic hyperinflation involves two components: static and dynamic. In the static component, trapped air is present without respiratory movements being restricted, while in the dynamic component, trapped air is dependent on respiratory rate and disappears during apnea.[2]

Hyperinflation is one of the principal causes of feelings of dyspnea, which are a common symptom of asthma,[10] although this varies from patient to patient even when they have the same degree of airflow obstruction.[5] The severity of asthma has at least two common dimensions, which are not always related: (a) baseline function, i.e. an instantaneous snapshot of respiratory conditions during the period between crises, which may included static hyperinflation; and (b) disease lability, i.e. the combination of bronchial hyperreactivity and response to treatment. Baseline function is linked to the degree of dysfunction, the control indicator for which is measurement of VEF_1, but which can also be monitored by recording peak expiratory flow daily.[11-13]

The effects of bronchoconstriction on pressures and respiratory muscle recruitment have been studied under a range of clinical conditions with several different age groups.[14,15] Acute narrowing of the airways is linked with dynamic hyperinflation,[16,17] which, among other characteristics, reduces the end-expiratory volume, reducing VEF_1 which in turn, at the end of a chain of mechanical compensations, results in persistent inspiratory muscle tone during expiration,[5,18,19] causing dynamic hyperinflation during acute asthma crises. After the crisis, incomplete reversion of mechanical respiratory parameters contributes to chronic trapped air which, if it accumulates, leads to residual or cumulative hyperinflation.[11,20]

There is no established consensus on how pulmonary trapped air is distributed within the chest, but there are many strategies to measure and explain each theory, almost all of them developed for adults.[5] Since the chest is a key factor in accommodating the hyperinflation volume in all theories,[14,18] the objective of this study was to develop a photogrammetric method capable of identifying increases in anteroposterior chest diameters relative to the transverse diameter, suggestive of pulmonary hyperinflation, and to then test it with both asthmatic and asthma-free children.

Methods

The data contained in this article combines the partial results of two projects to develop instrumentation for pediatric kinematic analysis. In conformity with resolution 196/96-CNS, both projects were approved by the relevant ethics committees, one being the Research Ethics Committee at the Hospital de Clínicas/Universidade Federal do Paraná (HC/UFPR) in Curitiba, PR, Brazil, and the other being the Research Ethics Committee at Unifesp, São Paulo, SP, Brazil. Parents or guardians of all participants provided informed consent before they were enrolled on the study.

Study design and triage of the sample

The data analyzed originate from analysis of images taken of a total of 56 children aged 8 to 12 years, divided between two subsets: a group of asthmatics (AS), comprising 19 children, and a subset of 37 non-asthmatic children (NA). In a joint partnership between UFPR and UNIFESP, the children in the AS were assessed at Pediatric Immunology, Allergy and Respiratory Medicine department's clinic at the HC/UFPR in Curitiba, PR, and at a specialist unit in Paranaguá, PR, while the NA group were selected at the Ear Nose and Throat Department at UNIFESP, in São Paulo, SP.

In São Paulo, 53 children of the same age, attending a full-time school (most schools in Brazil have two *shifts* per day – either students attend in the morning or in the afternoon/evening), were invited to take part in the study by means of sending their parents a consent form. Those who returned the form completed were asked selective questions about preexisting respiratory diseases, history of muscle pain, postural complaints, wearing spectacles and problems with balance. The 37 children who replied in the negative to all questions were enrolled for the study and made up the NA subset. In Curitiba, the asthmatic subset was made up of children on treatment for a minimum of 12 months and stable for at least 30 days who were evaluated between October and December of 2006.

Three modes were therefore defined for observation and analysis of the results from these two groups: (a) records for all 56 children, taken as a single group (GR); (b) a subset of 19 asthmatics (AS); (c) a subset of 37 non-asthmatic children (NA).

The system known as photogrammetry was used according to a routine, starting with preparation of the volunteer and progressing through image acquisition, processing and final reading of the measurements from the images.[21,22] For this process, self-adhesive circular white markers with a 13mm diameter were used to provide a visible reference at the height of the xiphoid process of the sternum (XI) and the anterior axillary fold (AX), positioned in such a manner as to be visible on images taken from both the angles to be used.

Photographs were taken in an orthostatic position at FRC, induced by a verbal command from the researcher for the child

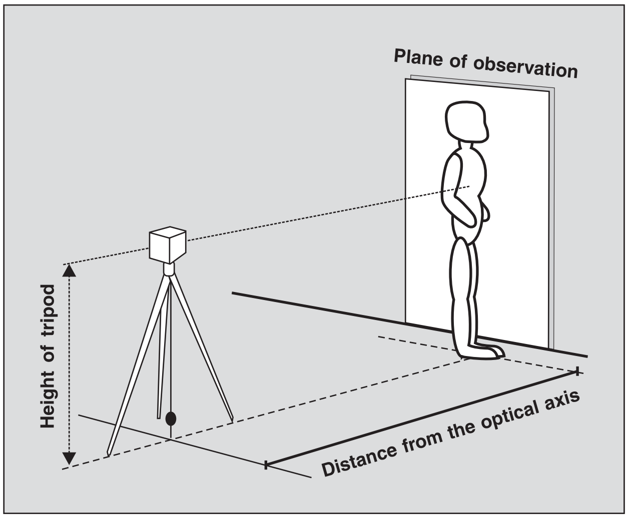
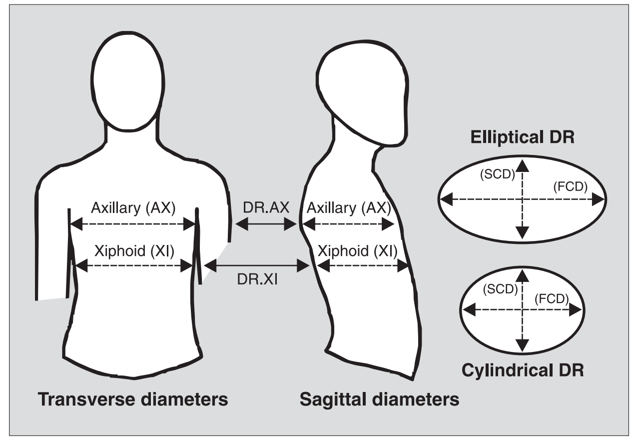


Figure 1 - Illustration of the position of the volunteer with relation to the camera mounted on its tripod



AX = axillary; DR = diameter ratio; FCD = front of child; SCD = side of child; XI = xiphoid.

Figure 2 - Points at which axillary and xiphoid measurements were taken on the front and right-side views. The diameter ratio (DR) calculated for each of these two heights represents one of two possible geometric shapes: either a DR representing an elliptical (physiological) chest, or a DR representing a cylindrical chest suggesting static hyperinflation, which is one of the characteristics of asthma

to breathe in deeply and then breath out, relaxing the shoulders. In order to make image acquisition systematic, four photographs were taken of each child, in the following sequence: starting with the rear and left side views, followed by shots from the angles actually of interest – the front and right side – which were the images used for analysis.

Photographs were taken using a Sony® digital camera mounted on a tripod 1.10 m from the floor, with the optical axis orthogonal to the measurement planes and set from 1.80 to 2.40 m away from the subject, depending on the height of each child (Figure 1). These digital images were then imported to CorelDRAW® version 12. Two chest diameters were traced on each image using the software's dimension tool: two diameters on the photo taken from the front of each child (FCD) and two diameters on the photo taken from the right side (SCD). Both the measures obtained of FCD and those of SCD, at the two heights of interest (AX and XI, Figure 2), constitute measures of proportionality within a given image for a given child.

Dividing SCD by FCD, for each of the two measurements (AX and XI), produced a dimensionless "diameter ratio" (DR) which was comparable between images of different children, irrespective of the distance from the camera. Geometrically, these DRs were used to represent the relationship between two perpendicular diameters of a circle, indicating a tendency to a cylindrical or oval shape (Figure 2). Trapped air at rest, or static hyperinflation, would be expected to be related to a DR tending to the cylindrical shape, which is typical of X-rays of hyperinflation.

The following statistical operations were performed on the DR values using SPSS version 13: (a) the Kolmogorov-Smirnov test was applied to GR, AS and NA, in order to test for normal distribution of the variables; (b) parametric tests were used to compare descriptive characteristics between each dataset; (c) the Pearson correlation test was applied by ranks, to test for intragroup correlations between DRs at XI and AX; (d) results were defined as significant at $p < 0.05$.

Results

Measurements were taken and analyzed from 56 children aged 8 to 12 years of age, 21 of whom were girls (37.50%) and 35 of whom were boys (62.50%). Sex distribution by presence or absence of asthma was 13 girls in the NA group (35.14%), and eight in the AS group (42.11%). The values observed for FCD and SCD were used to find the DRs for the groups GR (n = 56), AS (n = 19) and NA (n = 37), individually.

Table 1 lists the descriptive data obtained using the photogrammetric method at both levels, the DR.AX and DR.XI heights, together with their distributions at the 25th, 50th and 75th percentiles. The DR.XI results in the AS groups were significantly different ($p < 0.01$) from those in both GR and NA. The distribution by percentiles, especially at the 50th percentile, which is taken as the reference index, demonstrates that the lowest DR.AX and the highest DR.XI were both in group AS.

The *t* test for independent samples did not detect significant differences ($p > 0.05$) between the three sets in terms of DR.AX, the values of which were very similar to each other. In contrast, mean DR.XI was significantly ($p < 0.01$) greater in the AS group than in the GR or NA groups. Pearson's test of

Table 1 - Descriptive statistics for the diameter ratios of the three groups with their distributions in percentiles

Groups/Level	M±SD	25th percentile	50th percentile	75th percentile
GR (n = 56)				
DR.AX	0.779±0.072	0.740	0.783	0.824
DR.XI	0.808±0.053	0.766	0.783	0.843
NA (n = 37)				
DR.AX	0.785±0.065	0.754	0.796	0.833
DR.XI	0.784±0.077	0.756	0.776	0.807
AS* (n = 19)				
DR.AX	0.768±0.050	0.721*	0.761*	0.800*
DR.XI*	0.855±0.094*	0.778*	0.836*	0.918*

AS = asthmatic subset; DR.AX = diameter ratio at the height of the axilla; DR.XI = diameter ratio at the height of the xiphoid; GR = entire group; M = mean; NA = non-asthmatic subset; SD = standard deviation.
* Statistically significant difference ($p < 0.01$).

correlation was applied to the DRs within groups and detected a significant correlation between DR.AX and DR.XI in all groups, although the correlation was stronger in GR and NA ($p < 0.01$) than in AS ($p < 0.05$).

Discussion

The identification of static hyperinflation is the subject of much disagreement and is replete with differences of opinion between clinicians and researchers, but also involves a relevant factor: the constant search for strategies that increase the arsenal of viable resources for use in daily clinical practice.

If, on the one hand, significant hyperinflation can result in abnormal distribution of the tidal volume at rest between upper and lower compartments of the lungs,[5] on the other hand, when mild it can be a ventilatory strategy that helps keep minor airways open, with improved regional distribution of alveolar ventilation. During early childhood, up to the age of 4 years, this is considered a physiological strategy,[23,24] whereas, after 4 years of age, and for the rest of a person's life, the presence of hyperinflation will result in abnormal distribution of the tidal volume, modifying static and dynamic thoracoabdominal behavior.[23] With respect to this, Cassart et al. have demonstrated that for a given absolute pulmonary volume, the passive configuration of the rib cage is similar in normal and chronically hyperinflated people, which signifies that the difference between them resides in the point on the pulmonary compliance curve at which respiratory rest occurs.[16,25,26]

The different methods used to define the quantity of air retained in the lungs at the end of exhalation, depending on how the process has originated, have generated a glossary of specific vocabularies. Parameters or methods such as respiratory rest, FRC, dynamic hyperinflation and chronic hyperinflation determine the attribution of different meanings to each term, and should be analyzed in different manners. Relaxation volume or respiratory rest (Vrelax) corresponds to the volume of the respiratory system in static equilibrium, the point at which the elastic recoil pressures of lung and chest wall are equal and opposed.[3,5] The definition of FRC is the moment at which Vrelax is reached, during quiet breathing.[2] Acute increases in FRC, residual volume or TLC are defined as hyperinflation, even when caused by different kinesiopathological mechanisms, as long as they result in increased end-expiratory lung volume. According to Palecek, however, chronic hyperinflation has to be estimated by clinical examination and according to the reference values with all its disadvantages.[2]

Gibson wrote at length about relevant features of studies relating to the definition of hyperinflation, stating that the majority of studies carried out to detect hyperinflation were performed with samples predominantly made up of adults with emphysema and that the few studies of children that do exist investigate acute asthma.[5] The methodology presented here is based on that research, to the extent that Gibson pointed out that discrepancies observed when attempting to determine the presence of hyperinflation based on increased anteroposterior (AP) chest diameters were related to the method by which and time at which data were obtained. When data were recorded at TLC, there was no significant difference between chronic obstructive pulmonary disease (COPD) patients and controls. In such studies, the authors attributed the impression of increased AP chest diameter to a reduction in AP abdominal diameter, resulting from weakened muscles. In contrast, studies that measured chest diameters at FRC, found an increase in the ratio between AP and transverse diameters, i.e., the chest was more circular in emphysema patients and during acute asthma crises.[5]

This guided the study described here in two ways: (a) asthma severity classifications for volunteers in the AS group could not be a criterion for control of data, since the degree of pulmonary hyperinflation can exhibit different magnitudes for a given level of airflow obstruction in different patients.[4,5] This assumption led to the decision to make a fundamental binary distinction between DRs: children either had or did not have an AP diameter that was enlarged with relation to the transverse diameter; (b) photographs were taken at FRC, in an orthostatic position – under which conditions there would supposedly be a reduction in AP chest diameter at the height of the xiphoid[5,6,24,25] - and from the front and the side in order to make it possible to calculate the ratio between the two diameters measured at the same height, here defined as the DR.

The results obtained here for DRs were very similar to those observed by Martinot-Lagarde et al. Although the tendency to a cylindrical chest may be considered to be a relatively common morphometric characteristic among children, how can one explain this being the only significant finding, and one related specifically to the AS group, if not by the fact that DR.XI was greater in children who had a specific kinesiopathological predisposition to this condition: asthma? This finding can be taken as evidence that the significant increase observed exclusively in the DR.XI of the AS group is therefore the result of increased AP diameter, in analogy with a sequence of mechanical events consistent with the presence of static hyperinflation in this group.[24]

The heights chosen to measure chest diameters were chosen in agreement with the morphofunctional consideration of Kondo et al., according to whom the AX and XI heights would signify an internal correlation with the chest and would be sensitive to static hyperinflation, due to the resulting mechanical adaptations.[6,26] The AX is correlated internally with the tracheal bifurcation, and XI correlates with the top of the diaphragmatic cupola.[6] Those authors recognize that an increase in AP diameter alone is not a determinant of the presence of hyperinflation, but consider that a valid explanation for the restricted significance of DR.XI in AS to be a strategy for accommodating the hyperinflation, as the diaphragmatic cupola descends and the area of apposition reduces.[27] Following this line of reasoning, only the DR at the XI would be directly affected by the increased AP diameter,[26,28] which is what was detected by the photogrammetry-based DR system.

Notwithstanding, the greatest relevance of this study is not the determination of hyperinflation using photogrammetric examination, but the promising tool that photogrammetry may prove to be for clinical management of conditions that induce hyperinflation, particularly asthma. This relevance is increased if one takes into account the fact that, when dealing with small children with asthma, invasive methods to achieve the same end cannot be used with frequency, whether because of possible ill-effects, costs or unavailability of equipment at health centers located far from large urban areas.

In asthma, the increased respiratory effort[23] and the feeling of dyspnea can be of varying levels of intensity, combining dynamic hyperinflation during crises with limited airflow due to chronic edema of the airways. Even if these conditions are present, the remainder of the physical examination may appear to be normal.[9,28] The importance of the DR photogrammetry methodology lies in its longitudinal application for clinical follow-up, allowing periodic intrapatient comparisons of thoracoabdominal geometry, making it possible to identify the moment at which hyperinflation begins to limit the capacity of the respiratory muscles to generate negative intrathoracic pressure,[9,19] to worsen the relationship between diaphragm length and tension, due to descent of the cupola at FRC,[20,26,27] and to deteriorate the contractile performance of the diaphragm and its capacity to adapt to changes in load and respiratory rate.[29]

These results are an invitation to reflect on and debate the mechanisms of static hyperinflation in asthma, proposing a feasible alternative resource,[30] although further studies are still needed to go into greater depth about reference values by age group and the relationship between DR indices and disease classification. The fact that it is possible to use the photogrammetry DR method in healthcare environments such as primary care units, hospitals, clinics and homes, means that there is a good chance that it will be adopted by physicians and/or physiotherapists. Were such a diffusion to take place, it would enable the discussion of new evidence from cohorts, integrating semiological data with mathematical findings.

It can be concluded that the development of DR methodology using photogrammetry has proven satisfactory and feasible for the identification of increased DR.XI in AS, suggestive of static hyperinflation, and merits further application in future studies in the area of pediatric respiratory medicine.

Acknowledgements

The authors are grateful to the Otorhinolaryngology Department at Unifesp, SP, Brazil, for their partnership in this study and to the specialist asthma control and treatment centre, the Grupo de Apoio ao Programa de Educação Respiratória (GAPER), based in Paranaguá, PR, Brazil, for the help provided.

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