Brief Communication

Assessing the impact that external factors have on respiratory mechanics assessed using a specific photogrammetric model*

Impacto de fatores externos sobre a mecânica respiratória avaliada por um modelo fotogramétrico específico: biofotogrametria

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Abstract

This is a report on a methodological adaptation of the photogrammetric technique, which is used in other medical specialties, for use in analyzing respiratory movements. Photogrammetry and a model of photogrammetry designated *biofotogrametria para análise da mecânica respiratória* (BAMER, photogrammetric analysis of respiratory mechanics) were tested under previously described pathophysiological conditions: post-exercise dynamic hyperinflation using positive end-expiratory pressure. The BAMER model identified an increase in the thoraco-abdominal area following exercise using positive end-expiratory pressure. These results are comparable to those obtained with more robust systems of respiratory kinematics. The use of photogrammetry has value in many areas, since it produces quantitative data, being particularly relevant in pediatrics, in which monitoring resources are scarce.

Keywords: Biomechanics; Photogrammetry; Respiratory mechanics; Thoracic wall.

Resumo

Este é um relato sobre a adaptação metodológica da técnica fotogramétrica, utilizada em outras especialidades, para análise do movimento respiratório. A biofotogrametria e o modelo denominado biofotogrametria para análise da mecânica respiratória (BAMER), foram testados em uma condição fisiopatológica previamente descrita: a presença de hiperinsuflação dinâmica após exercício com uso de pressão expiratória final positiva. O modelo BAMER identificou um aumento da área tóraco-abdominal após exercício com uso de pressão expiratória final positiva, resultado este comparável aos obtidos por sistemas mais robustos em cinemática respiratória. A pesquisa em biofotogrametria possui valor relevante para muitas áreas, posto que agrega dados quantitativos, sendo particularmente relevante na pediatria, onde o monitoramento é escasso.

Descritores: Biomecânica; Fotogrametria; Mecânica respiratória; Parede torácica.

In pulmonology, although impairment of the respiratory mechanics is not restricted to individuals with respiratory diseases,[1] it can produce results of relevant proportions in such individuals. To study the kinetic aspects of respiratory pathology, one must have knowledge of respiratory mechanics and kinematics in order to identify and quantify imbalances of the respiratory muscles, as well as seeking out new technologies,[2] as observed in other medical specialties. Equipment for objective monitoring[1,3] is scarce, and those developed in laboratories are occasionally incompatible with the Brazilian public health care system scenario.

In this panorama, movement analysis systems using imaging, whose adaptation[4] as a noninvasive monitoring technique has gained ground in state-of-the-art research, have been successfully used in the analysis of body segment movements in functional or diagnostic activities in other medical specialties,[2,5] principally in orthopedics and neurology. In pulmonology, such systems provide biomechanical,[6] morphometric[7] and kinematic evidence,[8-11] involved in respiratory diseases or not, and can be applied in different scenarios while maintaining quality and reproducibility.[11] The type of photogrammetry used in study[5,12,13] represents a promising trend, whose operational differentiation from traditional photogrammetry is in the methodological improvement for the analysis of respiratory movement.

This communication presents the performance of photogrammetry in the identification of quantitative alter-

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ations in the lateral area of the trunk, induced by the use of positive end-expiratory pressure (PEEP), using a geometric model, following exercise under controlled conditions. We worked with three male volunteers who were between 40 and 45 years of age, with no history of smoking and with normal spirometric test results. The study was approved by the Ethics in Human Research Committee of the Federal University of Paraná *Hospital das Clínicas*.

In a model consisting of irregular quadrilaterals over anatomic reference points of the trunk, traced over recorded video images of maximum respiratory maneuvers, we used photogrammetry to calculate the differences between the area of each constituent quadrilateral measured prior to controlled exercise in a stationary cycle ergometer and that measured after the exercise. The exercise was the landmark for the question problem: would the areas of the model, at the end of the test with PEEP, be larger and prone to be detected by photogrammetry when compared to the areas prior to exercise? In order to answer this question, two 30 min exercise tests were performed, with a one-week interval between the two. The tracing of the thoraco-abdominal area of the first test result became the control for comparison with the second test, using PEEP.

The tests were performed at 60% of the heart rate reserve, the first test being considered a control

for cardiorespiratory reactions to load. In the second test, performed at the same time of day one week following the first test, the same conditions and load were applied, in addition to using an oronasal mask attached to a unidirectional valve for expiratory delay set at 5 cmH$_2$O PEEP. The PEEP was introduced 5 min prior to the beginning of the exercise in order to adapt the subject to the equipment. It is of interest that, even during the introduction of the mask, without any valve/load, modifications were observed in the thoraco-abdominal behavior.

A Sony TRV-140 camcorder with a shutter speed of 1/60 s, optical axis perpendicular to the sagittal plane of the evaluated individual, and elevated 1.50 m above the floor on a tripod was used to record five respiratory maneuvers at a time, of which only the three intermediate maneuvers were analyzed for each volunteer. The maneuvers were performed from residual volume to total lung capacity and had been previously practiced. The camcorder remained in the same position throughout the experiment, being activated by remote control, for comparative records among tests in the images referring to the time points: time point 1 (pre-exercise for the first test); time point 2 (post-exercise for the first test); time point 3 (pre-exercise for the second test, with mask and without the load valve); time point 4 (after 3 min of quiet ventilation, for adaptation to
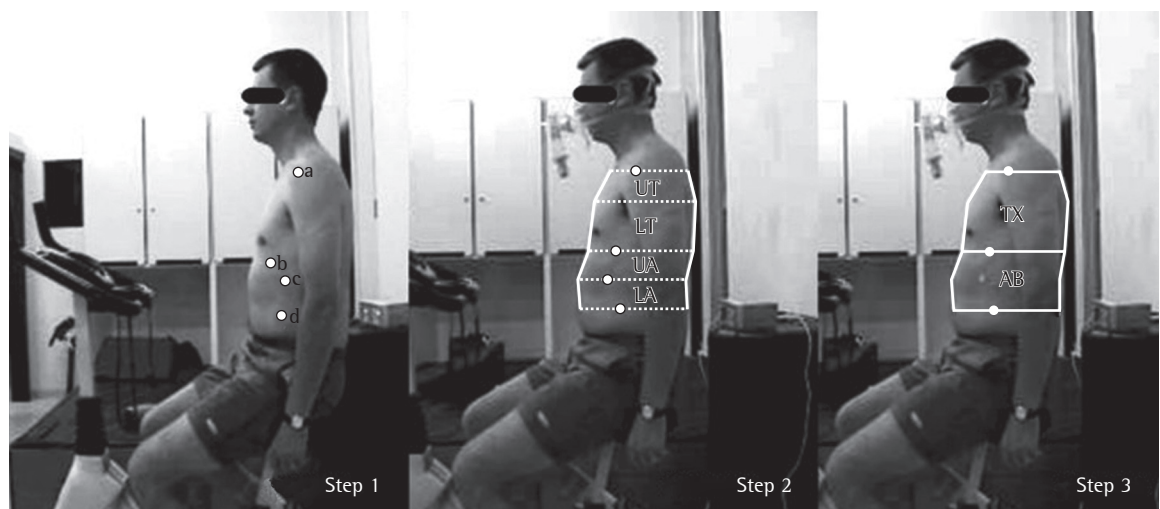
Figure 1 – Photogrammetric analysis of respiratory mechanics model. Step 1: Surface markers delineating the chest wall: (a) acromioclavicular joint, (b) level of xiphoid process; (c) lower angle of the cartilage of the 10th rib (d) umbilicus level. Step 2: Fractioning of the chest wall into four sub-compartments: upper thoracic (UT), lower thoracic (LT), upper abdominal (UA) and lower abdominal (LA). Step 3: division of the thoracic wall into thoracic (TX) and abdominal (AB) compartments.

the equipment with PEEP set at 5 cmH$_2$O expiratory load at the pre-exercise for the second test level); and time point 5 (post-exercise with PEEP).

In order to facilitate identification in the film, the delimitation of the chest wall was highlighted by the distribution of white flat spherical markers, 13 mm in diameter, by the same examiner. The markers remained in place throughout the experiment at the following locations: a) the acromioclavicular joint; b) the xiphoid process; c) the costal arch of the 10th rib; and d) the level of the umbilicus.

Studies which established references for studies on respiratory kinematics[7,14-18] laid the foundation for the model of irregular quadrilaterals. Planes transverse to the references were drawn, and the extent of the chest wall was delineated from the level of the acromioclavicular joint in the upper portion to the level of the umbilicus in the lower portion (Figure 1, Step 1). This line was divided at the level of the xiphoid process[15] (Figure 1, Step 3) into thoracic and abdominal compartments. Other studies[16,18] permitted advancement, with additional divisions, so that each compartment became two new sub-compartments (Figure 1, Step 2). Therefore, a plane at the level of the anterior axillary fold divided the thoracic compartment into upper and lower thoracic sub-compartments; the same occurred for the abdominal compartment, where a plane at the level of the lower angle of the 10th rib cartilage delineated the upper and lower abdominal

sub-compartments. The limits were traced by lines on the silhouette of the body surfaces, anteriorly and posteriorly. The final set was designated *biofotogrametria para análise da mecânica respiratória* (BAMER, photogrammetric analysis of respiratory mechanics).

The images captured at each proposed time point were extracted form the footage using the software Corel-R.A.V.E.® 3 (Corel Corporation, Ottawa, Canada). Over those, the BAMER model was traced using Corel-Draw® version 12 (Corel Corporation) and, subsequently, the areas were measured using AutoCAD® 2005 (Autodesk Inc., San Rafael, CA, USA), having the area of one of the surface markers, with an area corresponding to 1.69 cm^2, as a calibrator for the conversion. This sequence of procedures equaled the framing of the images recorded on different days, that is, it established a line of identity among the results, which were submitted to statistical treatment in the Statistical Package for the Social Sciences, version 13.0 (SPSS Inc., Chicago, IL, USA), and values of $p \leq 0.05$ were considered statistically significant.

Table 1 gathers the median values obtained from the nine inspiratory and expiratory maneuvers of the three studied subjects, at each time point analyzed, for each division of the model. However, it is important to observe that even in a small trial, the performance of the model confirmed the suspicion of the central argument: there was evidence

Table 1 – Median of the inspiratory and expiratory values in cm^2 for the chest wall areas in each compartment and sub-compartment of the photogrammetric analysis of respiratory mechanics model.*

Compartment or sub-compartment	Time point 1		Time point 2		Time point 3		Time point 4		Time point 5	
	Insp	Exp	Insp	Exp	Insp	Exp	Insp	Exp	Insp	Exp
UT	36.469[a]	34.223	29.789	28.573	33.348[a,b,c,d]	32.418[d]	30.078[c,d]	29.349[d]	30.047[a,b]	30.212[a]
LT	64.095[a]	65.845	50.474	52.256	56.553[a,b,c]	57.288	57.593[c]	56.637	54.587[b]	49.968
UA	29.586	21.140	28.899	27.289	27.190[c]	23.598	28.887[c]	23.598	34.353	22.485
LA	44.771[a]	31.906	34.529	31.144[e]	23.323[a,b,d]	17.981[d]	23.526[a,d]	18.267[d]	29.888[b]	19.332[e]
TX	101.077[f]	100.070[a]	79.303[g]	80.627	90.652[f,c,d,h]	89.091[a,d]	86.583[f,c,i,j]	85.598[i]	83.751[g,h,j]	82.739
AB	68.527	59.685	60.174	54.909[e]	49.980	41.987	52.414[a]	40.239	68.817[a]	41.092[e]
CW	169.604[f]	163.412	138.325	135.606	140.225[a,f,c]	131.694	137.410[c]	125.837	153.125[a]	121.619

*Same letters represent significant (p < 0.05) comparative correlations. Time point 1: pre-exercise for the first test; Time point 2: post-exercise for the first test; Time point 3: pre-exercise for the second test, with mask and without the load valve; Time point 4: after 3 min of quiet ventilation, to adapt to the equipment with positive end-expiratory pressure (PEEP), set to 5 cmH$_2$O of expiratory load during the pre-exercise for the second test; Time point 5: post-exercise with PEEP; Insp: measurement of maximum inspiratory time; Exp: measurement of maximum expiratory time; UT: upper thoracic sub-compartment; LT: lower thoracic sub-compartment; UA: upper abdominal sub-compartment; LA: lower abdominal sub-compartment; TX: thoracic compartment; AB: abdominal compartment; and CW: chest wall.

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of active hyperinflation following the exercise performed using PEEP, detectable by the BAMER model.

Studies with PEEP, applied at rest or during exercise, have shown an increase in the recruitment of respiratory muscle activity in different forms: the PEEP modified the level of functional residual capacity and the subsequent inspiratory dynamics.[14] The present study explored the hypothesis that the effect could be detectable through the use of the BAMER model.

The pre-exercise inspiratory areas differed for the thoracic compartment and the chest wall. At the pre-exercise time point, the thoracic area in the free test was larger than when PEEP was used, with or without load ($p < 0.01$); this difference was significant for the chest wall with mask and without load ($p < 0.05$). Considering the differentiated nature of the BAMER subdivision, the difference was detected in the upper and lower thoracic sub-compartments and in the lower abdominal sub-compartment, whose areas were larger ($p < 0.05$) at the pre-exercise time points without mask than those obtained with the mask and with load.

A 1996 study indicated an increase in the functional residual capacity due to cumulative effect of the expiratory delay at rest, using a 5 cmH_2O load. In the present study, the time of use of PEEP at rest was shorter and, although using the same load, no modifications in the thoraco-abdominal area were observed, or at any other BAMER division level.[14] However, at time points 3 and 4, the impact of the mask without load for the patient was identified by the reaction of the respiratory mechanics in significant alterations ($p < 0.05$) for the thoracic inspiratory areas and the chest wall, for which the BAMER presented variation of the measurements in the upper and lower thoracic sub-compartments and in the lower abdominal sub-compartments, and for the amplitude of the expiratory maneuvers, when the thoracic compartment was different for the modification of the upper thoracic sub-compartment as well as for alterations in the lower abdominal sub-compartment.

Studies involving magnetometry and respiratory inductive plethysmography[18] have shown an increase in abdominal muscle recruitment during free exercise, leading to a reduction in the abdominal end-expiratory volume, accompanied by a reduction in the thoracic end-expiratory volume.

The areas measured using BAMER corroborated the following statements: the thoracic inspiratory areas were larger at the post-exercise with PEEP time point ($p < 0.05$) than at the time points without expiratory load, and this was accompanied by a reduction in the expiratory area of the abdominal compartment ($p < 0.05$), explained by the reduction in that of the lower abdominal sub-compartment. Healthy subjects who exercised on a stationary cycle ergometer with PEEP[19] had increased pulmonary end-inspiratory volume, mostly due to the thoracic expansion, accompanied by a reduction in abdominal end-inspiratory volume. Similarly, when compared with the inspiratory areas prior to and following the same tests, there was difference ($p < 0.05$) for the thoracic compartment in the test with PEEP, that is, between the time point 3 and time point 5, as well as between time point 4 and time point 5.

Even though we still need ample scientific investigation, research into the type of photogrammetry used in this study[20] has contributed to pulmonology, since it is capable of aggregating quantitative data, giving objectivity to the analysis of respiration patterns and effectiveness in the identification of the kinetic and pathological variations associated with respiratory diseases. This group of contributions is particularly relevant in pediatrics, where resources for respiratory monitoring are scarce.

Therefore, although much remains to be explored, with due caution and rigor, until the definite validation of respiratory photogrammetry as used in this study becomes a reality, we believe that the pathway opened by the use of the BAMER model is promising. It is a relatively simple, low-cost resource, capable of identifying a known pathophysiological phenomenon, such as the increase in the thoraco-abdominal area following exercise using PEEP, as have the more robust systems in respiratory kinematics.

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