Elżbieta SZCZYGIEŁ[1,2]
Joanna KUMIĘGA[1]
Tadeusz MAZUR[3]
Joanna GOLEC[2,4]
Sylwia MĘTEL[2]
Dorota CZECHOWSKA[4]

Influence of the ageing process on the chest breathing movements

Wpływ wieku na ruchy oddechowe klatki piersiowej

[1]Department of Physiotherapy, Institute of Physiotherapy, Faculty of Health Sciences, Jagiellonian University Medical College, Cracow, Poland
Head:
Prof. Jan Bilski

[2]Department of Physiotherapy, Andrzej Frycz Modrzewski Krakow University, Cracow, Poland
Head:
Prof. Bogusław Frańczuk

[3]"Zdrowie" Rehabilitation Centre, Cracow, Poland

[4]Department of Rehabilitation in Orthopedics, Faculty of Motor Rehabilitation, Bronisław Czech University School of Physical Education, Cracow, Poland
Head:
Prof. Edward Golec

Słowa kluczowe:
biomechanika oddychania, ruchomość klatki piersiowej, wiek

Key words:
biomechanics of breathing, chest mobility, age

Correspondence Address:
Elżbieta Szczygieł,
Department of Physiotherapy, Institute of Physiotherapy, Faculty of Health Sciences, Jagiellonian University Medical College
31-126 Cracow,
ul. Michałowskiego 12
e-mail:elzbietasz@gmail.com

The aim of this work was the photogrammetric assessment of breathing movements in persons of different age. The clinical material comprised 106 study subjects, (55 women- 51,8% and 51 men- 48,2%) at the age between 18 and 90 years. The study subjects were classified in accordance with the age criterion into four groups (18 -30 yeas, 40 – 50 years, 60 -70 years, and the age of 80 years and more). The study was conducted with the use of the photogrammetric system PBE. The assessment of selected parameters was performed in an unconstrained position: at maximum inspiration, maximum expiration and intermediate position between maximum inspiration and maximum expiration. The record in three planes was applied: coronal (XY), transverse (XZ) and sagittal (YZ). The values of the angles characterizing the movement of the costal arch in the frontal, sagittal and tranverse plane were lower in the elderly. The results indicates the expiratory position of the chest in the elderly persons.

Celem pracy była fotogrametryczna ocena ruchów oddechowych osób w różnym wieku. Materiał kliniczny obejmował 106 osób (55 kobiet - 51,8% i 51 mężczyzn 48,2%) w wieku pomiędzy 18 a 90 lat. Zgodnie z przyjętym kryterium wieku osoby badane zostały zaklasyfikowane do czterech grup (18- 30 lat, 40– 50 lat, 60– 70 lat, powyżej 80 lat). Do realizacji celu pracy wykorzystano fotogrametryczny system oceny PBE. W przebiegu badań rozpatrywane były pozycje: pozycja swobodna na bezdechu, pozycja swobodna na maksymalnym wdechu, pozycja swobodna na maksymalnym wydechu. W badaniach wykorzystano zapis w trzech płaszczyznach: czołowej (XY), poprzecznej (XZ) i strzałkowej (YZ). Uzyskane wartości kątów charakteryzujące ruch łuków żebrowych w płaszczyźnie czołowej, strzałkowej i poprzecznej były niższe u osób starszych. Wyniki te wskazują na wydechowe ustawienie klatki piersiowej osób starszych.

Introduction

An efficient respiratory system constitutes the basis for proper functioning of the whole organism. Breathing is a phase activity, which refers to a fluent transition of the inspiration phase into the expiration phase. During the respiratory cycle, the work of respiratory muscles and diaphragm changes all chest wall dimensions. All immobilizations, chest deformities, pains, respiratory muscles paralysis, even temporary postural disorders can affect the chest mobility and, thus, significantly reduce the range of lungs ventilation [1,2,3]. Some authors suggest that aging processes also influence the quality of breathing movements. A number of changes that occur in connection with age, including, among others, ossification of costal cartilages and reduction of muscle strength can affect the chest mobility and, thus, change the breathing pattern [4,5,6].

Commonly applied spirometric studies inform about breathing movements and possible chest deformities only indirectly and to a small extent. The studies can be enriched with qualitative observations on the subject of breathing movements, with the use of the respiratory inductive plethysmography or of the opto-electronic plethysmography. A number of indications confirm that photogrammetry is a method allowing a detailed analysis of the chest mobility [7].

Methods

In order to achieve the aim of this work, photogrammetric study in the system Photogrametrical Body Explorer (PBE) was applied. PBE is a system positioning selected points of the entire human body, what allows to determine spatial coordinates of the selected body points and, thus, enables the analysis of motion in time [8]. The measurement is entirely remote. The form illustrates projections of measuring points combined with specific segments into three reference planes and tables with values of the angles between the selected segments.

The study comprised 106 healthy volunteers, (55 female, 51 male). The age of the study subjects ranged from 18 to 90 years. The overall mean age amounted to 49.03 years. Obesity (BMI

less than 30), neuromuscular and rheumatoid diseases and faulty posture, which could influence the study results, were not confirmed in the study group. None of the persons examined were being treated due to respiratory diseases. The study subjects were classified in accordance with the age criterion into four groups:

1. The first group comprised 30 persons at the age between 18-30 years (mean 27,42).
2. 30 persons aged 40-50 years were classified into the second group (mean 46,22).
3. The third group consisted of 30 persons aged 60-70 years (mean 65,81).
4. The fourth group included 16 persons at the age of 80 years and more (mean 81,25).

The persons studied were asked to assume subsequently defined body positions during which the measurements were performed. In the course of the studies for this work, the following standing positions were considered: unconstrained position, position at maximum inspiration, position at maximum expiration. The record in three planes was applied: coronal (XY), transverse (XZ) and sagittal (YZ). Only angular values of coordinates, which could prove the relationship with the chest breathing movements, were taken into consideration (Table I).

Methods of the statistical analysis

Analyses of the values of angles depending on the age group and moment of the performed measurements were analyzed by the one-factor (age) analysis of variance with repeated measurements (time of measurement). The analysis of the differences of changes of angles between inspiration and expiration, depending on the age, was analyzed by the one-factor analysis of variance and the Kruskal-Wallis test. In addition, the dependence of the difference between inspiration and expiration on the age was analyzed through the estimation of the Pearson's linear correlation coefficient and the Spearman's rank correlation coefficient. The testing probability at the level of $p<0.05$ was considered significant, whereas the testing probability at the level of $p<0.01$ as highly significant.

The protocol of study was approved by the Bioethical Commission in Kraków (No. 44/KBLOIL/2012).

Table I.
Values used in the chest mobility assessment

Values used in the chest mobility assessment	
C7_B S. YZ	The forward movement of the breastbone in the s agittal plane (the angle between the spinous process of the 7th cervical vertebra and incisura jugularis).
C7_S/Y S. YZ	The synkinesis of the spine in the sagittal plane (the angle between the spinous process of the 7th cervical vertebra and the point marked on the sacrum).
Y/XP_LCM S. XY	The movement of the left costal margin in the coronal plane
XP_RCM/Y S. XY	The movement of the right costal margin in the coronal plane
Y/XP_LCM S. YZ	The movement of the left costal margin in the sagittal plane
XP_RCM/Y S. YZ	The movement of the right costal margin in the sagittal plane (the angle between the xiphoid process and the point marked on the costal margin of the 10th left rib).
LCM_XP/RCM_XP S. XZ	The movement of costal margins in the transverse plane
Y/RS_C7 S. XY	The synkinesis of the right shoulder in the coronal plane
LS_C7/Y S. XY	The synkinesis of the left shoulder in the coronal plane (the angle between the acromial end of the clavicle and the 7th cervical vertebra).
RS_C7/C7_LS S. XZ	The movement of shoulders in the transverse plane.

Results

Movement of the breastbone in the sagittal plane

In the assessment of the breastbone movement in the sagittal plane no significant ($p=0.0766$) differences between results of the C7-B S. YZ angle, depending on age, were discovered. The interaction between the age groups and further measurements was not significant ($p=0.7707$). However, the difference between the values during inspiration and expiration was highly significant (< 0.0001). This denotes lower values of the C7-B S. YZ angle during expiration. Similarly, the comparison of the results obtained in the intermediate position and inspiration ($p<0.0001$) and between the results in the intermediate position and expiration ($p=0.0026$) showed highly significant differences. The results demonstrate a clear forward movement of the breastbone during inspiration and its return to the expiratory position, where the values are lower than in the intermediate position. The reduced breastbone mobility together with the age was not revealed.

Synkinesis of the spine in the sagittal plane

In the assessment of the spine movement in the sagittal plane in the respiratory process, highly significant ($p<0.0001$) differences of the values of the C7_S/Y S. YZ angle, depending on age, were discovered. Younger groups, i.e. 18-30 years and 40-50 years do not differ significantly ($p=0.5600$) and older groups of 60-70 years and 80 and more do not differ significantly ($p=0.3211$). The comparison of the group of 40-50 years with 60-70 years did not display a significant difference ($p=0.3165$). However, remaining comparisons of the

Table II.
The C7-B S. YZ angle (movement of the breastbone in the sagittal plane) depending on the time of measurement and age of the persons examined and the C7_S/Y S. YZ angle (synkinesis of the spine in the sagittal plane) depending on the time of measurement and age of the persons examined.

		The breastbone YZ			The spine YZ		
Age (yr)	mean	Intermediate position	Max. inspiration	Max. expiration	Intermediate position	Max. inspiration	Max. exspiration
18-30	SD	59,03	65,23	56,37	177,59	177,69	177,66
	mean	5,36	5,51	5,54	1,99	2,56	2,70
40-50	SD	61,11	67,79	60,27	176,69	176,69	176,58
	mean	6,26	6,46	7,09	2,73	3,26	2,94
60-70	SD	61,76	67,94	60,53	174,96	175,58	175,51
	mean	6,23	6,70	7,79	2,47	2,81	4,39
>80	SD	58,56	65,54	57,47	173,34	174,40	172,97
	mean	5,20	4,54	6,44	3,67	3,06	9,63
p_value (age)	0,0766				0,0001		
P_value (measurements)	< 0,0001				0,4036		
p_value (inspiration/expiration)	< 0,0001				0,7133		

older groups with the younger ones indicated significant differences between them. The difference between the group aged 18-30 years and 60-70 years was significant (p=0.0160), between the group aged 18-30 years and 80 and more - highly significant (p=0.0010), between the group of 40-50 years and 80 and more - significant (p=0.0190).
This indicates that the values of the C7_S/Y S. YZ angle in older groups were lower than in younger groups. These data disclose a leaning posture of the elderly. The difference of the measurement results during inspiration and expiration proved to be insignificant (p=0.7133).

Movement of the left and right costal margin in the coronal plane

In the assessment of the movement of the costal margins in the coronal plane, the following was discovered: highly significant (p<0.0001) differences in the values of the Y/XP_LCM S. XY and XP_RCM/Y S.XY angle, depending on age. Younger groups, i.e. aged 18-30 years and 40-50 years do not differ significantly (p=0.5837 left) (p=0.4313 right) and older groups of 60-70 years and 80 and more do not differ significantly (p=0.9037 left) (p=0.9096 right). However, the comparison of older groups with the younger ones indicated significant differences between them. The difference between the group aged 18-30 years and 60-70 years was highly significant (p=0.0002 left and right), between the group aged 18-30 years and 80 and more - highly significant (p=0.0004 left), (p=0.0005 right) between the group aged 40-50 years and 60-70 years - highly significant (p=0.0030 left), (p=0.0084 right) and between the group of 40-50 years and 80 and more - highly significant (p=0.0073 left) (p=0.0157 right). This means that the values of the Y/XP_LCM S. XY and XP_RCM/Y S.XY angles in older groups were lower than in younger groups. The difference of the measurement results during inspiration and expiration proved to be insignificant (p=0.2955 left) (p=0.1633 right). Similarly, the differences of the results obtained in the intermediate position and inspiration (p=0.9973 left) (p=0.9074 right) and between the results obtained in the intermediate position and expiration (p=0.2629 left) (p=0.3414 right) proved to be insignificant. The interaction between age groups and further measurements was insignificant (p=0.3128 left) (p=0.5195 right). The results indicate a small mobility of the right costal margin in all age groups and lower values in older groups indicate its expiratory position.

Table III.
Values of the Y/XP_LCM S. XY angle (movement of the left costal margin in the coronal plane) depending on the time of measurement and age of the persons examined and the Y/MD3_LL3 S. YZ angle (movement of the left costal margin in the sagittal plane) depending on the time of measurement and age of the persons examined

		Y/XP_LCM S. XY			Y/MD3_LL3 S. YZ		
Age (yr)	mean	Intermediate position	Max. inspiration	Max. expiration	Intermediate position	Max. inspiration	Max. exspiration
18-30	SD	142,00	141,88	142,00	176,74	177,12	175,95
	mean	6,57	6,50	6,95	8,30	7,87	8,47
40-50	SD	139,74	138,82	138,87	175,15	175,86	173,35
	mean	7,52	6,40	6,50	9,71	9,34	9,10
60-70	SD	131,21	131,65	130,73	172,15	170,77	170,04
	mean	10,55	10,70	10,39	16,95	17,57	17,66
>80	SD	128,98	129,96	128,44	164,07	165,47	161,58
	mean	11,29	10,92	12,14	11,89	12,67	13,25
p_value (age)	< 0,0001				0,0051		
P_value (measurements)	0,1449				0,0001		
p_value (inspiration/expiration)	0,2955				0,0006		

Movement of the left and right costal margin in the sagittal plane

In the assessment of the movement of the costal margin in the sagittal plane, the following was discovered: highly significant (p=0.0051 left) (p=0.0003 right) differences in the values of the Y/XP_LCM S. YZ and XP_RCM/Y S.YZ angle, depending on age. These differences mainly relate to the oldest group, i.e. of 80 and more years, which are significantly lower (p=0.0514 left) (p=0.0489 right) than the results of the group aged 40-50 years and significantly (p=0.0163 left) (p=0.0009 right) lower than the results of the group aged 18-30 years. The results of particular measurements were highly significantly different (p=0.0001 left) (p=0.0015 right).

However, the highly significant difference (p=0.0006 left) (p.=0.0024right) relates to the measurement during inspiration and expiration, and significant difference (p=0.0015 left) (p=0.0429 right) applies to the comparison of the results obtained in the intermediate position and during expiration. The measurements in the intermediate position and during inspiration do not differ significantly (p=0.9617 left) (p=0.6196 right).
Lower values of the angles in older age groups indicate the expiratory position of the chest.

Table IV.
Values of the Y/XP_LCM S. XY angle (movement of the left costal margin in the coronal plane) depending on the time of measurement and age of the persons examined and the Y/MD3_LL3 S. YZ angle (movement of the left costal margin in the sagittal plane) depending on the time of measurement and age of the persons examined

		Y/XP_LCM S. XY			Y/MD3_LL3 S. YZ		
Age (yr)	mean	Intermediate position	Max. inspiration	Max. expiration	Intermediate position	Max. inspiration	Max. exspiration
18-30	SD	142,00	141,88	142,00	176,74	177,12	175,95
	mean	6,57	6,50	6,95	8,30	7,87	8,47
40-50	SD	139,74	138,82	138,87	175,15	175,86	173,35
	mean	7,52	6,40	6,50	9,71	9,34	9,10
60-70	SD	131,21	131,65	130,73	172,15	170,77	170,04
	mean	10,55	10,70	10,39	16,95	17,57	17,66
>80	SD	128,98	129,96	128,44	164,07	165,47	161,58
	mean	11,29	10,92	12,14	11,89	12,67	13,25
p_value (age)	< 0,0001				0,0051		
P_value (measurements)	0,1449				0,0001		
p_value (inspiration/expiration)	0,2955				0,0006		

Movement of costal margins in the transverse plane

Significant differences (p=0.0266) in results of LCM_XP/RCM_XPS.XZ angle were observed, depending on the age. These differences mainly concern the oldest group, which are significantly lower (p=0.0398) than results of the group aged 18-30 years. The results of particular measurements were highly significantly different (p=0.0017). However, the significant difference (p=0.0108) relates to the measurement during inspiration and expiration and the highly significant difference (p=0.0046) relates to the comparison of results in the intermediate position and during expiration. The interaction between age groups and further measurements was insignificant (p=0.9619). The results show the expiratory position of costal margins in the transverse plane in older groups.

Synkinesis of the right and left shoulder in the coronal plane

In the assessment of the right shoulder movement in the coronal plane there were no significant (p=0.3954 right) (p=0.0529 left) differences observed between the results of the Y/RS_C7 S.XY and LS_C7/Y S. XY angle in relation to age.

For further measurements (the intermediate position, maximum inspiration, maximum expiration), a highly significant difference was observed (p<0.0001 right) (p<0.0001 left). The interaction between age groups and further measurements was insignificant (p=0.9378 right) (p=0.5146 left). The difference between the results during inspiration and expiration was highly significant (p<0.0001 for the right and left). This indicates lower results of the Y/RS_C7 S.XY and LS_C7/Y S. XY angles during expiration. Similarly, the comparison of the results obtained in the intermediate position and inspiration demonstrated a highly significant difference (p<0.0001 for the right and left), whereas between the results in the intermediate position and expiration a significant difference was observed (p=0.0143 right) (p=0.0239 left). There were no differences shown in its position in various age groups, however, its significant mobility in the positions: inspiration - expiration, intermediate position - expiration, intermediate position - expiration was demonstrated.

Movement of shoulders in the transverse plane

No significant differences (p=0.0529) were observed between the results of the RS_C7/C7_LS S XZ angle in relation to age.

Table V.
Values of the Y/RS_C7 S.XY and LS_C7/Y S. XY angle (synkinesis of the right and left shoulder in the coronal plane) and RS_C7/C7_LS S. XZ (movement of shoulders in the transverse plane) depending on the time of measurement and age of the persons examined.

		Y/RS_C7 S.XY			LS_C7/Y S. XY			RS_C7/C7_LS S. XZ		
Age (yr)		Intermediate position	Max. inspiration	Max. expiration	Intermediate position	Max. inspiration	Max. expiration	Intermediate position	Max. inspiration	Max. expiration
18-30	mean	73.93	78.04	72.72	73.47	77.89	72.47	44.56	50.15	44.83
	SD	4.02	4.24	3.82	4.35	4.42	3.91	8.94	8.4	8.56
40-50	mean	75.37	79.93	75.07	76.64	80.37	75.75	43.59	48.87	44.47
	SD	4.49	4.80	4.72	4.95	4.93	4.97	9.28	9.45	10.48
60-70	mean	74.97	78.94	73.72	74.89	78.15	73.95	45.2	50.84	45.8
	SD	10.55	5.74	4.81	5.11	5.42	5.73	7.7	6.63	6.97
>80	mean	74.32	78.79	73.64	72.87	78.03	72.73	43.98	49.73	44.18
	SD	4.66	4.72	5.20	4.22	5.25	5.37	11.38	11.31	10.51
p_value (age)			0.3954		0.05			0.8964		
P_value (measurements)					<0.0001			<0.0001		
p_value (inspiration/expiration)			<0.0001		<0.0001			<0.0001		
p_value (interaction)			0.9378		0.5146			0.9897		

In case of further measurements (the intermediate position, during inspiration, during expiration), a highly significant difference was observed (p<0.0001). The interaction between age groups and further measurements was insignificant (p=0.9897).

The difference between the results during inspiration and expiration was highly significant (<0.0001). This indicates lower results of the RS_C7/C7_LS S XZ angle during expiration.

Similarly, the comparison of the results obtained in the intermediate position and inspiration demonstrated a highly significant difference (p<0.0001), whereas between the results in the intermediate position and expiration no significant differences were observed (p=0.4914).

The angle illustrates movement of the right and left shoulder in the transverse plane (forward and backward shoulder movement). A significant mobility of shoulders was shown during inspiration (backward) and expiration (forward) and in the position: intermediate position - inspiration.

Table VI.
Difference in the values of particular angles between inspiration and expiration, depending on the age.

Difference in the values of particular angles between inspiration and expiration, depending on the age					
Difference	18-30 years	40-50 years	60-70 years	80 and more	Significance*
C7-B S.YZ	8.86	7.52	7.41	8.06	p^1=0.7366
	4.53	5.94	5.79	6.14	p^2=0.7710
XP_RCM/Y S.XY	0.03	0.67	0.50	1.75	p^1=0.4223
	1.68	3.24	2.82	5.81	p^2=0.9705
XP_RCM/Y S.YZ	1.66	1.52	2.32	3.91	p^1=0.5598
	3.64	6.26	6.80	6.04	p^2=0.6061
Y/XP_LCM S.XY	-0.12	-0.04	0.92	1.52	p^1=0.1838
	1.97	2.64	2.77	4.72	p^2=0.3343
Y/XP_LCM S.YZ	1.16	2.50	0.73	3.89	p^1=0.1580
	3.42	4.78	6.34	4.87	p^2=0.1401
LCM_XP/RCM_XP S.XZ	3.45	2.11	2.38	4.40	p^1=0.8375
	6.84	8.93	10.82	10.26	p^2=0.7550
C7_S/Y S.YZ	0.03	0.11	0.07	1.43	p^1=0.7286
	2.78	2.09	3.96	8.76	p^2=0.1277
Y/RS_C7 S.XY	5.32	4.86	5.22	5.15	p^1=0.9722
	3.19	3.86	4.47	4.11	p^2=0.9940
LS_C7/Y S.XY	5.42	4.62	4.20	5.30	p^1=0.5962
	2.88	3.40	4.64	4.26	p^2=0.8950
RS_C7/C7_LS S.XZ	5.32	4.39	5.04	5.55	p^1=0.8799
	4.23	6.54	5.38	4.34	p^2=0.9886

Discussion

Photogrammetric system is applied in many fields of medicine, mainly in the assessment of a posture and movement [9,10]. In this work, the photogrammetric method PBE was used in order to examine changes in the chest mobility. Angles determined between the markers, allowing to assess the movement in three planes of costal margins, breastbone, spine and shoulders, were subject to the study.

Janessens [4] and Oyarzún [11], confirm that with age the costal cartilages are subject to ossifications and the chest assumes expiratory position. The above mentioned belief was confirmed in the conducted studies. The analysis of values of the angles related to the mobility of costal margins revealed much lower values of the oldest group in comparison to younger groups. The studied angles of the right and left costal margin in the coronal, sagittal transverse plane do not indicate differences in the manner of mobility of lower ribs, depending on age groups. However, the expiratory position of the chest is clearly visible in the elderly. Beside of this the oldest group was showing much lower measurement values of spine movements. This may indicate changes occurring in the position of the spine in older persons and assumption of the hunched body position.

Conducted studies also revealed the asymmetry between the left and right side of the body. This phenomenon can be found in the literature, especially during the studies of walk [12,13]. Taking into consideration both right and left costal margin in the coronal plane, higher values of the angle on the right side are noticed in all age groups and in all positions. This tendency is confirmed also in the analysis of the values of the angles related to the right and left costal margin in the sagittal plane. In the sagittal plane the angle of the left costal margin was characterised by higher values than the angle of the right costal margin. This means that the left side, in most of the cases, assumes more expiratory position than the right side.

Our observations, applying to the asymmetry of the chest, have no confirmation in the literature of the subject. Regnarsdóttir reports that breathing movements were symmetrical [14]. The registered discrepancies can be explained with the use of different measurement methods and with different positions of patients during the study. Regnarsdóttir conducted the study in an isolated supine position that could deform the breathing chest movements. In the studies presented it was a standing position.

Despite the revealed differences in the position of ribs, indicating the expiratory position of the chest in older persons, no differences were observed in the manner of breathing that could result from age differences. These observations are confirmed in the works of other authors using different measurement methods. Verschakelen drew a conclusion that the volumemotion coefficients obtained during quiet breathing were not influenced by sex or age [15]. Britto also drew a conclusion that there were no significant differences between the groups regarding breathing patterns, respiratory variables and thoracoabdominal motion. These findings suggest that the ageing process of the respiratory system reduces the inspiratory muscle strength but does not have a significant impact on breathing pattern variables [16]. Similar conclusions were drawn by Parriera [17] and Ragnarsdótt [14]. Verschakelen as well as Britto and Parreira conducted their studies with the application of inductive plethysmograph, and Ragnarsdóttir using the RMMI.

Conclusions

The results indicates the expiratory position of the chest in the elderly persons. The aging process reduces inspiratory muscle strength but does not have a significant impact on breathing pattern.

References

1. **Donath J, Miller A.** Restrictive chest wall disorders. Semim Respir Crit Care Med 2009;30:275-292.

2. **Koumbourlis AC.** Scoliosis and the respiratory system. Paediatr Respir Rev 2006;7: 152-160.

3. **Szczygieł E, Rojek M, Golec J, Klimek E, Golec E.** Forced postural distortions and the level of selected spirometric values. Orthop Quart 2010;3:439 – 451.

4. **Janssens JP, Pache JC, Nicod LP.** Physiological changes in respiratory function associated with ageing. Eur Respir J 1999;13:197-295.

5. **Rossi A, Ganassini A, Tantucci C, Grassi V.** Aging and the respiratory system. Aging 1996;8:143-161.

6. **Zeleznik J.** Normative aging of the respiratory system. Clin Geriatr Med 2003;19:1-18.

7. **Szczygieł E, Łopatka K, Malec A, Mazur T, Handzlik J, Kaczor J.** Photgrammetric analysis of chest mobility of men and women. Physiotherapy theory and practise. U.J. Krakow 2012:77-91.

8. **Tokarczyk R.** Automatyzacja pomiaru na obrazach cyfrowych w systemie fotogrametrycznym do badania wad postawy. University Academic and Instructional Publishing House AGH. 2007, Kraków.

9. **Cappozzo A, Della Croce U, Leardini A, Chiari L.** Human movement analysis using stereophotogrammetry. Part 1: theoretical background. Gait Posture 2005;21:186-196.

10. **Gabor LR, Chamberlin AP, Levy E, Perry MB, Cintas H, Paul SM.** Digital stereophotogrammetry as a new technique to quantify truncal deformity: a pilot study in persons with osteogenesis imperfecta. Am J Phys Med Rehabil 2011;90:844-850.

11. **Oyarzún GM.** Pulmonary function in aging. Rev Med Chill 2009;137:411-418.

12. **Szczygieł E, Król S, Grzebień P, Golec J, Mętel S, Golec E.** The analysis of accelerometric variables in subjects walking barefoot and high heels. Orthop Quart 2010;3:404- 416.

13. **Takakura K, Fujiwara S, Yamaguchi T.** Functional differences between dominant and non-dominant lower limbs in compensatory stepping. Neuroscience Research 2009;65;169.

14. **Ragnarsdóttir M, Kristnidóttir EK.** Breathing movements and breathing patterns among healthy men and women 20-69 years of age. Respir 2006;73:48-54.

15. **Verschakelen JA, Demedts MG.** Normal thoracoabdominal motions. Influence of sex, age, posture, and breath size. Am J Respir Crit Care Med 1995;151:399-405.

16. **Britto RR, Zampa CC, de Oliveira TA, Prado LF, Parreira VF.** Effects of the aging process on respiratory function. Gerontology 2009;55:505-510.

17. **Parreira V, Bueno CJ, Franca DC, Vieira SR, Perceira DR, Britto RR.** Breathing pattern and thoracoabdominal motion in healthy individuals: influence of age and sex. Rev Bras Fisioter 2010;14:411-416.