Analysis of biomechanical, spirometric and muscle strength patterns in the thoracic-abdominal cavity of paraplegic athletes

Eliane Maria de Carvalho; Jullyne Ferreira Carvalho; Célia Regina Lopes,

Valdeci Carlos Dionisio

Key-words: Breathing mechanics; biophotogrammetry; spirometry; muscle strength; biomechanics.

Abstract

Introduction: Spinal cord trauma is considered one of the most severe and debilitating injuries.

Objective: To assess lung volume and capacity, breathing muscle strength, and thoracic-abdominal configuration before and after placement of the abdominal band.

Methodology: Were measured volume and pulmonary capacity using an portable spirometer, the pressure maximal inspiratory (MIP) and expiratory (MEP), analysis of the thoracic-abdominal movement. Next, an elastic abdominal band was used.

Results: Twenty five volunteers paraplegic were assessed: 15 men and 10 women. When the initial and final values of forced vital capacity, forced expiratory volume and peak expiratory flow were analysed, it was found that the values were statistically significant for women, all being below the predicted value. The MIP values before and after the placement of abdominal band were analysed, it was found that the values were statistically significant for men, although women had MIP values similar to the predicted one MEP values were statistically significant for both. The Charpy's angle decreased during inspiration.

Conclusion: The elastic abdominal band can improve the breathing mechanics, mainly in women. Also, the thoracic-abdominal movement is impaired in individuals with spinal cord injuries.

Keywords: Breathing mechanics; biophotogrammetry; spirometry; muscle strength; biomechanics.

Introduction

The movements of thoracic and abdominal deformation occurring during ventilation are strongly related to these functional and physiological aspects, thus being the targets of interest for knowledge and characterisation of the ventilation patterns. With regard to healthy individuals, several studies have found an association between ventilatory movements of thorax and abdomen and volume of air exchanged between lungs and environment (Levine et al 1991, Cala et al 1996). Other studies were conducted to differentiate ventilatory movements in terms of gender (Verschakelenand, Demedts 1995), age (Estenne et al 1985, Poulin et al 1999), position during breathing (Barnas et al 1993), physical activities (Aliverti et al 1997), and contribution of thorax and abdomen to ventilation (Cala et al 1996, Ward et al 1992).

There are controversies in the literature about the normal values of maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) in healthy individuals. Studies show that men have significantly higher values for MEP and MIP compared to women (Souza 2002, Wilson et al 1984), with maximal respiratory pressures reaching peak values in young adults and declining progressively with age (Harik-Khan et al 1998). These factors seem to be correlated with differences in body dimensions between genders as men. In general, present greater respiratory muscle force and higher values of functional residual capacity (FRC), total pulmonary capacity (TPC), and residual volume (RV) compared to those found in women (Pande et al 1998, Neder et al 1999). With regard to age, there is a change in lung elasticity and thoracic cavity as well as a decrease in muscle mass and strength, which may affect the respiratory pressure values (Harik-Khan et al 1998).

On the other hand, there are still little data on individuals suffering from other lesions, such as the spinal cord trauma (SCT) (Schilero et al 2009, Roth et al 1997, Estenne & De Troyer 1987, Krassioukov 2009). SCT is considered one of the most severe and debilitating injuries and whose victims are mostly young adults. Traumatic lesion of the spinal cord is a major cause of morbidity and mortality, resulting in permanent changes both physically and socially. Mild and severe motor and sensory deficit below the lesion, vasomotor dysfunctions, autonomic and sphincterian alterations, and sexual dysfunction are some of the outcomes (Spungen et al 2009). Respiratory muscle strength and pulmonary function may also be compromised. It was found that the pulmonary function of an individual with cervical SCT is impaired because of the biomechanical change of the thoracic cavity (Ledsome 1981). This occurs due to the paralysis of abdominal and intercostal muscles, including total or partial loss of the diaphragmatic function in some cases. Depending on the spinal cord injury level, the current respiratory volume (CRV) in supine position decreases by 60%, and individuals with injuries below the fifth cervical segment have decreases of 30% in their CRV during the first week following the trauma (Ledsome 1981).

Pulmonary complications are the major causes of morbidity and mortality in individuals with SCT (Devivo et al 1993, Linn et al 2001, Aito 2003, Brown et al 2006). Paralysis of the inspiratory muscles is characterised by the individual's inability to have a prolonged inspiratory flow, contributing to hypoventilation (Spungen et al 2009, Ledsome et al 1981, Hass et al 1985, Loveridge et al 1990). Because individuals with SCT adopt a sitting posture most of their time, it would be interesting to analyse the pulmonary function as the breathing mechanics could be changed. In fact, respiratory efficacy depends on adequate costo-abdominal coupling as well as on the integrity of inter-costal, diaphragmatic, and abdominal muscles (Goldman et al 1973). In this sense, the use of abdominal band could be an auxiliary mechanism to improve the respiratory function. Although some studies have investigated the effect of abdominal bands on the breathing mechanics of healthy individuals and those with SCT, there is still no consensus on the benefits of this type of abdominal contention (Wadsworth et al. 2009).

The objective of this work was to assess volume, pulmonary capacity, respiratory muscle strength, and thoracic-abdominal movement during breathing manoeuvres before and after placement of the abdominal band. We have tested the hypothesis that individuals with SCT would benefit from the use of elastic abdominal band, improving their pulmonary volume and muscle strength. The other hypothesis that men present respiratory parameter values higher than women has been also tested.

Method

The protocol was approved by the local human research ethics committee (number 697878). Thirty individuals with SCT who practice Paralympics modalities were studied. None of them was smoker or had lung disease. Individuals presenting abdominal or thoracic scar, pain, lung disease, neurological and/or muscular disorder were excluded from the study.

For anthropometric evaluation, the volunteer’s weight and height were recorded to calculate the body mass index (BMI). A previously calibrated portable spirometer (OneEasy model 2001, Zurich, Switzerland) was used for complete evaluation of the pulmonary function according to norms established by the American Thoracic Society (ATS 1999). In this way, it was possible to assess forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), and peak expiratory flow (PEF).

Maximal inspiratory (MIP) and expiratory pressures (MEP) were obtained from residual volume (RV) and total pulmonary capacity (TPC), respectively, by using a manovacuometer (Globalmed, Brazil) operating between -150 to 150 cmH_2O. The manovacuometer was adapted to a 1-mm orifice nozzle in order to prevent glottis closure and pressure dissipation caused by the facial and oropharyngeal muscles (Black & Hyatt 1969). The measurements were obtained from the volunteers in sitting position and wearing a nasal clip. Inspiratory and expiratory efforts were held for at least 1 second. Three measurements were consecutively made, and the highest value was recorded. However, if the last measurement was higher, the procedure was repeated once again.

The lateral-lateral expansibility of the thorax was analysed by means of biophotogrammetry (Figueroa et al 2003, Erlingsson et al 2009) in which points of the thorax regarding the twelfth ribs bilaterally and xiphoid process are considered, thus delimiting the Charpy’s angle. The individuals were instructed to inspire deeply, followed by inspiratory pause and subsequent maximal expiration. The tasks were recorded with digital camera (Sony) and the images quantified by using the Alcimage software version 2.1.

The subjects accepted for study were submitted to the pulmonary function test, followed by biophotogrammetric analysis of the muscle strength. The recovery time for these tasks was about 30 minutes. After these evaluations, an elastic band was placed around the abdomen so that the abdominal circumference was reduced by 5%. The elastic band involved the whole abdominal region below the twelfth rib to the antero-superior iliac spine (Zamataro 1999).

Statistic Analysis

The spirometric measurements, muscle strength and thoracic mobility were compared between athletes with abdominal band and those without it by means of Student-t test at 5% significance level.

Results

Of the 30 volunteers evaluated, five were excluded because they did not meet the measurement criteria. The remaining 25 volunteers, 15 males and 10 females, were included in the study (Table 1).

Table 1: Anthropometric data.

	Women	**Men**	**P**
Age (years	31.1 ± 7.1	33.0 ± 7.8	0.44
Weight (Kg)	70.0 ± 15.2	65.9 ± 15.3	0.54
BMI (Kg/m^2)	26.3 ± 4.4	22.7 ± 4.7	0.05*
AC (cm)	95.0 ± 10.1	83.5 ± 11.5	0.15
Band AC (cm)	90.5 ± 9.6	78.2 ± 11.2	0.13

Note: BMI = body mass index; AC = abdominal circumference; * P < 0.05

The results revealed that the values obtained from both men and women were lower than the predicted values (Tables 2, 3, and 4) regarding all variables studied before and after the use of abdominal band (P < 0.05).

FVC, FEV1, and PEF values were found to be significant for women and not for men after the use of elastic abdominal band (Tables 2 and 3).

Table 2: FVC, FEV1, and predicted mean values (± SD) for men and women.

	FVC (L) without band	**FVC (L) with band**	**Predict value**	**FEV1 [L] without band**	**FEV1 [L] with band**
Women	3.03 ± 1.0	3.29 ± 0.68*	3.56 ± 0.36	2.08 ± 1.1	2.48 ± 0.5*

Men	3.77 ± 0.95	3.91 ± 0.95	4.80 ± 0.39	3.27 ± 1.1	3.44 ± 0.7

Note: FVC = forced vital capacity; FEV1 = forced expiratory volume in the first second; * P < 0.05.

Table 3: Peak Flow Expiratory and predicted mean values (± SD) for men and women.

	PEF (L/min) without band	**PEF (L/min) with band**	**Predicted value**
Women	5.48 ± 2.42	5.83 ± 2.20*	6.68 ± 1.29
Men	7.46 ± 2.40	7.99 ± 2.21	11.07 ± 2.21

Note: PEF = peak expiratory flow. * P < 0.05.

The use of abdominal band produced higher MIP values only for men, whereas MEP values were found to be higher for both genders (Table 4).

Table 4: Mean values of maximal inspiratory and expiratory pressures and predicted values for men and women with and without abdominal band.

	MIP		**Predicted**	**MEP**		**Predicted**
	without band	**with band**		**without band**	**with band**	
Women	96.2 ± 30.7	100.8 ± 28.6	88.7 ± 3.6	85.0 ± 32.8	95.4 ± 43.9*	154.1 ± 3.8
Men	98.0 ± 31.6	105.7 ± 29.3*	124.8 ± 4.2	97.7 ± 33.2	108.4± 48.2*	234.0 ± 4.4

Note: MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure. * P < 0.05 Using Black and Hyatt (1969) equations.

With regard to the analysis of thoracic expansibility and mobility, it was observed a decrease in the Charpy's angle during inspiration in both genders (Table 5). Significant variation in the Charpy's angle was also found in women (8 degrees) and men (11 degrees) for deep breathing at rest.

Table 5: Mean values of Charpy's angle during maximum inspiration and expiration at rest.

Charpy's angle	**At rest**	**Inspiration**	**Expiration**

Women	128.1 ± 11.8	119.9 ± 12.2*	130.8 ± 10.2
Men	127.9 ± 12.0	116,3 ± 13.1*	123.6 ± 11.3

Discussion

This study was aimed at assessing pulmonary volumes and capacities, respiratory muscle strength and thoracic-abdominal movement during breathing measurements before and after placement of abdominal band. The results revealed difference in BMI between men and women, being higher in the latter. This difference may be related to the estrogen as women have more body fat than men. In fact, estrogen decreases the woman's ability to burn energy, resulting in more fat deposition throughout the body (Erlingsson et al 2009).

Abdominal fat deposition can directly reduce the diaphragmatic mobility, whereas fat deposition on the thoracic wall can decrease the movement of the thoracic cavity and cause thoracic complacency, thus resulting in restrictive pattern. Wannamethee et al 2005 suggest that abdominal fat deposition leads to a redistribution of the blood to the thoracic cavity, which reduces the vital capacity. These authors found an association between FEV1 and an increase in morbidity and mortality, since obesity impairs the pulmonary function.

However, the BMI does not take into account the pattern of fat distribution or body composition. Due to the immobilisation in a wheelchair and the injury, fat is predominantly deposited on the abdomen (Wannamethee et al 2005). Increase in BMI is associated with several chronic-degenerative diseases, generally involving a reduction in the pulmonary parameters (Kronander et al 2004, Poulain et al 2006). As a result, the obesity-related risks to health include effects on respiratory system in association with the level of obesity and presence and distribution of abdominal fat (Mancini 2001, Delorey et al 2005).

In addition to the metabolic alterations, fat accumulation might also be related to a poor muscle efficiency of the abdominal muscles,, thus facilitating fat deposition on the region of the abdomen. Compared to men, women have less muscle strength according to the Black & Hyatt's equation (1969), which can enhance the body fat deposition (Wannamethee et al 2005, Kronander et al 2004, Poulain et al 2006). The increased muscle strength also might explain the improved value of MIP and MEP among men following use of abdominal band, whereas women had only their MEP improved. This suggests that the diaphragmatic function could not be improved despite the help from the abdominal band. Alternatively, one can suppose that the 5% compression produced by the elastic band was not enough to change significantly the abdominal pressure in men.

Men with SCT characteristically have abdominal deficits (Boaventura et al 2003, Andrada et al 2001, Estenne et al 1987) and this might explain the behaviour seen for Charpy's angle, also called infrasternal angle (Ramos 1986). It has been shown that during the inspiration process there is an increase in the lateral-lateral diameter as well as a slight antero-posterior displacement, that is, there would be an increase in the

Charpy's angle during inspiration (Goldman et al 1973, Kapandji 2000, D'Angelo et al 1999). The findings obtained in the present study have revealed a reduction in this angle. Such a reduction may also be related to abdominal deficits, as the action of the muscles of the abdomen is important to limit the visceral movements during inspiration. This allows the diaphragm to complete loop movements and aperture of lower ribs (Estenne et al 1987), thus producing an increase in the Charpy's angle. This resistance imposed upon the diaphragm improves the zone of apposition, allowing a better thoracic expansibility. Therefore, the abdominal deficits may be the key factor for the results found in the present study despite the difference in BMI between the groups.

Boaventura et al. (2003) have analysed the pulmonary volumes of paraplegic subjects in sitting and spine positions and after use of abdominal band. The authors described that elastic abdominal band can improve respiratory function because it allows mechanical support and produces increase in abdominal pressure, thus favouring the biomechanics of muscles and thoracic cavity. Abdominal contention increases the contraction of the diaphragm (Koulouris et al 1989, Hillman et al 1990). The benefits of abdominal compression on respiratory function have been reported elsewhere (Schilero et al 2009, Bolser et al 2000).

Spinal cord-injured individuals wearing elastic abdominal band had improvement in their spirometric and pressure parameters, mainly in the sitting position (Barnas et al 1993, Erlingsson et al 2009). However, Wadsworth et al (2008) described in their study review that the use of elastic abdominal band improves the vital capacity on one hand, but decreases the functional residual capacity on the other hand. These authors found a decrease in FVC, FEV1 and PEF. These findings are similar to those reported by other studies in which restrictive functional characteristics are secondary to the paralysis of abdominal muscles. They also reported that besides the weakness and paralysis of the respiratory muscles, restrictive disturbance is secondary to the decreased thoracic complacency (Andrada et al 2001).

Therefore, several studies corroborate our findings for women as their values for FVC, FEV1 and PEF (Wilson et al 1984, Hillman et al 1990, Andrada et al 2001) were improved, whereas others partially supported the findings for men regarding these same variables (Pande et al 1998, Neder et al 1999).

The use of elastic abdominal band improves the spirometric and pressure parameters, mainly in the sitting position (Goldman et al 1973, Zamataro 1999), as the diaphragmatic elevation is balanced by an enlargement of the lower thoracic cavity, producing muscle stretching and maximum muscle contraction for force generation.

Conclusion

The elastic abdominal band can improve the breathing mechanics, mainly in women. Also, the thoracic-abdominal movement is impaired in individuals with spinal cord injuries.

Acknowledgement

The research team sincerely thanks the Association of Paraplegics the Uberlândia (APARU) and Foundation Uberlandense Tourism Sport and Leisure (FUTEL) for support needed for this research study.

References

Aito S (2003). Complications during the acute phase of traumatic spinal cord lesions. Spinal Cord, 41(11);629-35.

Aliverti A, Cala SJ, Duranti R. et al (1997). Human respiratory muscle actions and control during exercise. J Appl Physiol, 83(4);1256-69.

American Thoracic Society (1999). Pulmonary rehabilitation. Am J Respir Crit Care Med 159;1666–1682.

Andrada L and Vito El (2001). Evaluacion functional respiratória en pacientes com lision medular traumática alta. Medicina, Buenos Aires, 61(5);.529-534.

Barnas GM, Green MD, Mackenzie CF. et al (1993). Effect of posture on lung and regional chest wall mechanics. Anesthesiol, 78(2);251-9.

Black LF and Hyatt RE (1996). Maximal respiratory pressures: normal values and relationship to age and sex. Am Rev Resp Dis, 103:641-50.

Boaventura CM, Gastaldi AC, Silveira JM et al (2003). Effect of abdominal binder on the efficacy of respiratory muscle seated and supine tetraplegic patients. Physiotherapy, 89(5);290-295.

Bolser DC, Reier PJ, Davenport PW (2000). Responses of the anterolateral abdominal muscles during cough and expiratory threshold loading in the cat. J Appl Physiol, 88(4);1207-14.

Brown R, Dimarco AF, Hoit JD (2006). Respiratory dysfunction and management in spinal cord injury. Respir Care, 51(8);853-68.

Cala SJ, Kenyon CM, Ferregino G et AL (1996). Chest wall and lung volume estimation by optical reflectance motion analysis. J Appl Physiol, 81(6);.2680-96.

D'Angelo E, Gligio R, Lafontainr E et al (1999). Influence of abdomen on respiratory mechanics in supine rabbits. Respir Physiol, 115(3);287-99.

Delorey DS, Wyrick BL, Babb TG (2005). Mild-to-moderate obesity: implications for respiratory mechanics at rest and during exercise in young men. International Journal of Obesity, 29(9);1039-1047.

Devivo MJ, Black KJ and Stover SL (1993). Causes of death during the first 12 years after spinal cord injury. Arch Phys Med Rehabil, 74(3);248-54.

Erlingsson S, Herard S, Dahlqvist Leinhard O et al (2009). Men develop more intraabdominal obesity and signs of the metabolic syndrome after hyperalimentation than women. Metabolism, 58(7);995-1001.

Estenne M, Yernault JC, De Troyer A (1985). Rib cage and diaphragm-abdomênn compliance in humans: effects of age and posture. J Appl Physiol, 59(6);1842-8.

Estenne M and De Troyer A (1987). Mechanism of the postural dependence of vital capacity in tetraplegic subjects. Am Rev Respir Dis, 35(2);367-71.

Figueroa PJ, Leite NJ, Barros RML (2003). A flexible software for tracking of markers used in human motion analysis. Computer Methods and Programs in Biomedicine, 72(2);155-65.

Goldman MD and Mead J (1973). Mechanical interaction between the diaphragm and rib cage. Journal of Applied Physiology, 35(2);197-204.

Haas F, Axen K, Pineda H et al (1985). Temporal pulmonary function changes in cervical cord injury. Arch Phys Med Rehabil, 66(3);139-44.

Harik-kan RI, Wise RA, Fozard JL (1998). Determinants of maximal inspiratory pressure. The Baltimore Longitudinal Study of Aging. Am J Respir Crit Care Med, 158(5):1459-64.

Hillman DR, Markos J, Finucane KE (1990). Effect of abdominal compression on maximum transdiaphragmatic pressure. J Appl Physiol, 68(6);2296-304.

Kapandji IA (2000). Fisiologia articular. São Paulo, Ed Manole, 3;142-161.

Koulouris N, Mulvey DA, Laroche CM et al (1989). The effect of posture and abdominal binding on respiratory pressures Eur Respir J, 2; 961-965

Krassioukov A (2009). Autonomic function following cervical spinal cord injury. Respir Physiol Neurobiol, 169(2);157-64.

Kronander UN, Falkenberg M, Zetterstrom O (2004). Prevalence and incidence of asthma related to waist circumference and BMI in a Swedish community sample. Respiratory Medicine, 98(11);1108-1116.

Ledsome JR and Sharp JM (1981). Pulmonary function in acute cervical cord injury. Am Rev Respir Dis, 124(1):41-4.

Levine S, Silage D, Henson D et al (1991). Use of a triaxial magnetometer for respiratory measurements. J Appl Physiol, 70(5);2311-21

Linn WS, Spungen AM, Gong HJR (2001). Forced vital capacity in two large outpatient populations with chronic spinal cord injury. Spinal Cord, 39(5);263-8.

Loveridge BM and Dubo HI(1990). Breathing pattern in chronic quadriplegia. Arch Phys Med Rehabil, 71(7);495-9.

Mancini MC (2001). Obstáculos diagnósticos e desafios terapêuticos no paciente obeso. Arquivo Brasileiro Endocrinologia Metabolismo, 45(6); 584-608.

Neder JA, Andreoni S, Lerario MC et al (1999). References values for lung function tests. II. Maximal respiratory pressures and voluntary ventilation. Braz J Med Biol Res, 32;719-27.

Pande JN, Verma SK, Singh SPN et al (1998). Respiratory Pressures in normal Indian subjects. Indian J Chest Dis Allied Sci, 40(4);251-6.

Poulain M, Doucet M, Major GC et al (2006). The effect of obesity on chronic respiratory diseases: pathophysiology and therapeutic strategies. CMAJ, 174(9);1293-9.

Poulin MJC, Paterson DA, Rechnitzer PA et al (1999). Normal thoracoabdominal motion. Monaldi Arch Chest Dis, 54930;287-8.

Ramos JJ (1986). Semiotécnica da observação clínica: fisiopatologia dos sintomas e sinais. São Paulo: Ed. Sarvier.

Roth EJ, Lu A, Primack S et al (1997). Ventilatory function in cervical and high thoracic spinal cord injury. Relationship to level of injury and tone. Am J Phys Med Rehabil,76(4);262-7.

Schilero GJ, Spungen AM, Bauman WA et al (2009). Pulmonary function and spinal cord injury. Respir Physiol Neurobiol, 66(3);129-41.

Souza RB (2002). Pressões respiratórias máximas. J Pneumol, 28(3);155-65.

Spungen AM, Bauman WA, Radulovic M et al (2009). Pulmonary function and spinal cord injury. Respir Physiol Neurobiol, 166(3);129-41.

Verschakelen JA, Demedts MG (1995). Normal thoracoabdominal motions. Influence of sex, age, posture, and breathe size. Am J Respir Crit Care Med, 151(2);399-405.

Zamataro VCO. Utilização da Cinta Abdominal Elástica em Pacientes Portadores de Trauma Raquimedular Alto. Relatos de Caso. Fisioter. Univ. São Paulo, 1(6);113- 121.

Wadsworth BM, Haines TP, Cornwell PL et al (2008). Abdominal binder use in people with spinal cord injuries: a systematic review and meta-analysis.Spinal Cord. Spinal Cord, 47(4);274-85.

Wannamethee SG, Shaper AG, Whincup PH (2005). Body fat distribution, body composition, and respiratory function in elderly men. Am J Clin Nutr, 82(5);996-1003.

Ward ME, Ward JW, Macklem PT (1992). Analysis of human chest wall motion using a two-compartment rib cage model. J Appl Physiol, 72(4);1338-47.

Wilson SHJ, Cooke NT, Edwards RHT et al (1984). Predicted normal values for maximal respiratory pressures in Caucasian adults and children. Thorax, 39;535-538.