G. Katsaris
A. Loukos
J. Valavanis
M. Vassiliou
P. K. Behrakis

The immediate effect of a Boston brace on lung volumes and pulmonary compliance in mild adolescent idiopathic scoliosis

Received: 4 November 1997
Revised: 2 September 1998
Accepted: 19 October 1998

G. Katsaris · M Vassiliou
P. K. Behrakis (✉)
Department of Experimental Physiology,
Medical School, University of Athens,
75, M. Asias St,
Athens GR-11527, Greece
Tel.: +301-6925501, Fax: +301-6490979

A. Loukos
Intensive Care Unit,
Red Cross Hospital of Athens,
Athens, Greece

J. Valavanis
Orthopedic Clinic, KAT General Hospital,
Athens, Greece

Abstract Idiopathic scoliosis (IS) is known to result in lung volume and pulmonary compliance reduction. Boston brace treatment of IS is an additional factor causing restrictive respiratory syndrome due to external chest wall compression. Nevertheless, the immediate effect of Boston bracing on the pulmonary compliance of scoliotic patients has not been studied systematically. Spirometric and plethysmographic lung volumes, static lung compliance ($C_{ST(L)}$) and specific lung compliance ($C_{ST(L)}/\text{functional residual capacity}$) of 15 scoliotic adolescents (14 females and 1 male, of mean age 14.1 ± 1.67 years, with mean Cobb angle $24.1^\circ \pm 7.88^\circ$) were recorded twice, in a random sequence: once without the Boston brace (nBB) and once immediately after wearing the brace (BB). Our findings showed

that bracing reduced vital capacity, residual volume, functional residual capacity (FRC), total lung capacity, and forced expiratory volume in 1 s in a proportional and significant way ($P < 0.001$). $C_{ST(L)}$ was also significantly reduced ($P < 0.001$), but $C_{ST(L)}/\text{FRC}$ remained unaltered. All BB and nBB indices were highly correlated. We concluded that Boston bracing in IS patients results in an immediate, predictable, and uniform reduction of lung volumes and pulmonary compliance. The reduction of $C_{ST(L)}$ under bracing conditions was related to the decrease of lung volume; the $C_{ST(L)}/\text{FRC}$ remained unaltered.

Key words Idiopathic scoliosis · Boston brace · Pulmonary function tests · Pulmonary compliance

Introduction

Idiopathic scoliosis (IS) is the most common disorder affecting the thoracic cage during adolescence [15]. Conservative treatment includes the use of a thoraco-abdominal plastic jacket, the “Boston brace” [25]. The jacket exerts an external pressure on the upper abdomen and lower chest wall, tending to correct the spinal deformity. Such a pressure would be expected to restrict respiratory movements, resulting in changes in lung volumes and pulmonary mechanics.

The effect of chest strapping on respiratory mechanics has been extensively studied in normal subjects by several

authors [3, 12, 22, 24], who suggest that static lung compliance ($C_{ST(L)}$) is reduced. This reduction is primarily dependent on lung volume decrease due to strapping. Yet, the overall result of Boston bracing on pulmonary mechanics in scoliotic patients remains unclear. $C_{ST(L)}$ per se has been studied in scoliotic patients [4], but the immediate effect of bracing on the $C_{ST(L)}$ has not been systematically examined. In addition, the effects of bracing on lung volumes are unclear in the literature. In previous studies, most authors have reported significant lung volume reduction [10, 11, 18], whereas others have not found considerable changes in vital capacity (VC) [23].

The purpose of our study was to measure the immediate effect of Boston brace treatment on lung volumes and

Fig. 1 The Boston brace (A) and a patient wearing the brace (B) in frontal and lateral view

$C_{ST(L)}$ and to investigate the net effect of chest wall bracing on pulmonary compliance in IS patients.

Materials and methods

Fifteen adolescents treated with the Boston brace (Fig. 1) for mild IS were included in the present study. Their physical characteristics and pulmonary function data are presented in Table 1. The non-deformed height was estimated from arm-span measurement using the regression equation proposed by Hibbert et al. [7]. None of the patients was a smoker or had cardiorespiratory symptoms. None had ever been treated either with brace or spinal fusion. There was no evidence for congenital or neuromuscular origin of their scoliosis.

Vital capacity, residual volume (RV), functional residual capacity (FRC), total lung capacity (TLC), forced expiratory volume in 1 s (FEV_1), $FEV_1/VC(\%)$, and static and specific ($C_{ST(L)}/FRC$) lung compliance were measured. Spirometric and plethysmographic lung volumes were recorded in the sitting position using the 1085D MedGraphics integrated pulmonary function testing system and were corrected to BTPS. Three measured values were recorded and the best one was kept. $C_{ST(L)}$ was measured by the esophageal balloon technique [16]. The validity of the technique as a measure of pleural pressure was tested with the "occlusion" test [2]. The test was performed by occluding the external airway at end-expiration and simultaneously recording the esophageal pressure (Pes) and mouth pressure (Pm) changes during the following two or three occluded inspiratory efforts. The ratio of Pes to Pm during this test was in all instances close to unity. Transpulmonary pres-

Table 1 Physical characteristics and lung function parameters with (BB) and without (nBB) Boston brace for 15 adolescents with idiopathic scoliosis (VC vital capacity, RV residual volume, FRC functional residual capacity, TLC total lung capacity, FEV_1 forced expiratory volume in 1 s, $C_{ST(L)}$ static lung compliance, $C_{ST(L)}/FRC$ specific lung compliance)

No.	Sex	Age (years)	Height (cm)	Cobb angle (°)	VC (l)		RV (l)		FRC (l)		TLC (l)		FEV_1 (l)		$FEV_1/VC (\%)$		$C_{ST(L)}$ (l/cm H ₂ O)		$C_{ST(L)}/FRC$ (cm H ₂ O ⁻¹)	
					nBB	BB	nBB	BB	nBB	BB	nBB	BB	nBB	BB	nBB	BB	nBB	BB	nBB	BB
1	F	11	156	27	2.2	2.0	0.8	0.7	1.4	1.1	3.0	2.7	2.0	1.9	89	95	0.11	0.09	0.08	0.08
2	F	15	167	15	3.3	2.7	1.3	1.0	2.4	2.0	4.6	3.7	2.6	2.1	80	78	0.17	0.15	0.07	0.08
3	F	12	163	40	2.6	2.4	1.0	0.8	2.0	1.7	3.6	3.2	2.4	2.1	91	87	0.13	0.10	0.07	0.06
4	F	14	171	19	3.3	3.0	1.5	1.3	2.5	2.2	4.8	4.3	3.1	2.9	94	97	0.23	0.18	0.09	0.08
5	M	13	151	35	2.2	1.9	1.6	1.0	1.9	1.9	3.2	2.9	2.1	1.8	93	95	0.12	0.10	0.06	0.06
6	F	15	175	25	3.3	3.2	1.6	1.2	2.5	2.2	4.9	4.4	2.8	2.7	86	86	0.12	0.09	0.05	0.04
7	F	15	161	33	2.4	2.2	1.8	1.7	2.8	2.6	4.2	3.9	2.4	2.1	100	98	0.15	0.13	0.05	0.05
8	F	12	163	18	3.2	2.5	1.2	1.0	2.1	1.6	4.4	3.5	2.8	2.4	89	94	0.19	0.16	0.09	0.10
9	F	17	171	20	3.7	3.5	1.3	1.2	2.5	2.3	5.0	4.7	2.9	2.8	77	78	0.19	0.19	0.08	0.08
10	F	15	156	18	3.0	2.6	1.2	0.9	2.3	1.8	4.2	3.5	2.6	2.5	88	94	0.15	0.12	0.06	0.07
11	F	13	150	30	1.7	1.6	0.9	0.8	1.4	1.1	2.6	2.4	1.6	1.4	97	91	0.09	0.08	0.06	0.07
12	F	16	152	15	2.7	2.4	1.7	1.6	2.5	2.2	4.4	4.0	2.6	2.4	88	100	0.27	0.23	0.11	0.10
13	F	13	160	20	2.8	2.3	1.0	1.0	2.0	1.7	3.8	3.3	2.6	2.2	93	96	0.14	0.12	0.07	0.07
14	F	15	167	29	2.8	2.3	1.2	0.9	2.2	1.7	4.0	3.2	2.5	2.2	88	93	0.14	0.10	0.06	0.04
15	F	15	165	17	3.5	3.0	1.5	1.4	2.8	2.0	5.0	4.4	3.1	2.9	89	95	0.21	0.21	0.08	0.10
Mean		14.1	161.9	24.1	2.8	2.5	1.3	1.1	2.2	1.9	4.1	3.6	2.5	2.3	89.5	91.8	0.16	0.14	0.07	0.07
SD		1.67	7.72	7.88	0.56	0.51	0.30	0.30	0.43	0.42	0.75	0.68	0.41	0.43	5.85	6.71	0.051	0.047	0.016	0.020
					83.2 ^a		132.9 ^a		101.1 ^a		93.4 ^a		79.4 ^a		95.8 ^a					

^aPercentage of the mean nBB parameter value compared to the corresponding mean value of the control group

Fig.2 Scatter diagrams and regression lines for measured lung function parameters (*VC* vital capacity, *RV* residual volume, *FRC* functional residual capacity, *TLC* total lung capacity, *FEV₁* forced expiratory volume in 1 s, *C_{ST(L)}* static lung compliance, *C_{ST(L)}/FRC*

specific lung compliance). Abscissa: values without Boston brace (nBB); ordinate: values immediately after wearing the Boston brace (BB)

sure was obtained by subtraction of P_{es} from P_m . Lung volume changes were obtained by electronic integration of the airflow measured at the mouth by a Fleisch 3 pneumotachograph. The pressure, flow, and volume recording systems were calibrated prior to each study. $C_{ST(L)}$ was calculated as the slope of the pressure-volume curve in the range of tidal volume, and was obtained from the deflation curve after maximal inflation. The mean value of three $C_{ST(L)}$ measurements was stored as the representative $C_{ST(L)}$ value, which, divided by the previously calculated FRC, gave the $C_{ST(L)}/FRC$.

The data of each patient were recorded twice: once without the Boston brace (nBB) and once with the brace (BB), in a random sequence. All measurements were performed after establishing resting breathing and reproducing similar efforts, estimated by the signals on the visual display. The BB measurements started 10 min after wearing the Boston brace. Fifteen normal adolescents matched for sex, age, and height were included in a control group. The study was approved by the ethics committee of our institution, and written consent was signed by the parents. Statistical analysis involved *t*-tests and linear regression analysis. The statistical significance level was set at 95% ($P = 0.05$).

Results

The values of all studied pulmonary function variables in the IS group under nBB and BB conditions are presented in Table 1.

VC was decreased in all patients during BB and the average decrease in comparison to nBB (12%) was significant ($P < 0.001$). FEV_1 was also decreased in every patient under BB and the average decrease in comparison to nBB (9.3%) was significant ($P < 0.001$). Statistically significant decreases were also observed in RV, FRC, and TLC ($P < 0.001$), with corresponding mean differences 15.8%, 15.6%, and 12.3%. $FEV_1/VC\%$ showed a slight (2.6%) but not significant tendency to increase under BB. $C_{ST(L)}$ was lower during BB for all studied patients and the mean decrease (14.8%) was statistically significant ($P < 0.001$). However, $C_{ST(L)}/FRC$ mean values were almost identical in both the BB and nBB measurements. The impairment of lung volumes and static lung compliance due to bracing was not related to the angle of scoliosis.

Scatter diagrams with the corresponding regression lines are presented in Fig. 2. All studied pulmonary func-

tion parameters showed a high degree of correlation between BB and nBB. Regression equations and correlation coefficients (r) are included in Table 2. Values of r are very high and the correlation was highly significant ($P < 0.001$) in all instances, proving that the calculated models are suitable to express the relation between BB and nBB for all parameters.

Comparisons between the control and the IS groups (the latter under nBB) showed that in the IS patients group VC and FEV_1 were lower, whereas RV was higher (corresponding mean differences: 16.8%, 20.5%, and 32.9%, $P < 0.001$). Differences for FRC (−1.1%) and TLC (+ 6.6%) between the two groups were not significant. The $FEV_1/VC\%$ was higher in the control group than in the IS group ($P < 0.05$).

Discussion

Thoracic braces have been widely used in the conservative management of patients with mild progressive idiopathic scoliosis [6, 17, 19, 21]. As long as scoliosis is a restrictive respiratory condition, the clinician should focus on the pulmonary function consequences of a treatment, which acts as an additional external restriction. Many authors have described the influence of thoracic bracing on some lung function parameters using different types of braces [10, 11, 18, 23]. The Boston brace is a widely used type, which affects not only the lung volumes, but also the elastic pulmonary behavior and rib cage-spine coupling [1].

According to our results in IS patients, Boston bracing caused an immediate, significant, and uniform decrease in VC, RV, FRC, TLC, and FEV_1 , in comparison to the nBB state. These findings, in combination with the unaltered FEV_1/VC ratio, suggested the immediate induction of a restrictive ventilatory defect due to the Boston brace application. The percentage reduction of these lung volumes lay within a relatively narrow range (9.3–15.6%), indicating a uniform effect of BB on lung volumes and capacities.

Different results have been presented in the literature concerning the influence of thorax bracing on lung volumes of IS patients. A first report [23] indicated a non-significant reduction of VC, whereas more recent ones [10, 11, 13, 18, 20] suggest that decreases in lung volumes are significant. Our results are in agreement with the latter findings, although, we noted a smaller reduction of lung volumes. It seems that discrepancies concerning lung volume reduction during bracing may be attributed to differences between the characteristics of the studied groups – especially in the value of the Cobb angle – the techniques of measuring lung volumes, and the type of the bracing.

The effect of an external restriction imposed on the thoracic wall has been extensively studied by chest strapping of normal subjects. Previous reports [3, 12, 24] have

Table 2 Linear regression equations for measured lung function parameters (y parameter with Boston brace, x parameter without Boston brace)

Parameter	Regression equations
VC	$y = 0.047 + 0.864 x, r = 0.944$
RV	$y = -0.005 + 0.845 x, r = 0.869$
FRC	$y = -0.084 + 0.081 x, r = 0.909$
TLC	$y = 0.056 + 0.863 x, r = 0.953$
FEV_1	$y = -0.255 + 1.003 x, r = 0.956$
$FEV_1/VC\%$	$y = 16.569 + 0.841 x, r = 0.733$
$C_{ST(L)}$	$y = -0.007 + 0.896 x, r = 0.959$
$C_{ST(L)}/FRC$	$y = -0.005 + 1.07 x, r = 0.845$

$P < 0.001$ for all regression equations

shown that impressive reductions of VC (about 40%) and other lung volumes have followed an externally applied chest wall restriction. In our study, the volume reduction induced by the Boston brace was smaller (12% for VC). This difference may be attributed mainly to the fact that the Boston brace exerts a rather mild external compression on the chest wall compared to the greater restrictive tension applied during the experimental strapping of the thorax in the above-mentioned studies [3, 12, 24]. In addition, it should be mentioned that IS patients had an already established mild restrictive disorder due to the scoliosis itself. This observation is based on our data (Table 1) showing an average 20% reduction of spirometric lung volumes measured in IS patients under nBB conditions compared with corresponding measurements performed in the control group. These data of ours are in agreement with the findings of other authors detailing the spirometric effects of IS [5, 9–11, 14, 26]. Most important were the differences in the RV (increased in IS group), whereas FRC and TLC were the least affected indices, obviously because of the counterbalancing effect of IS on spirometric volumes (reduced in the IS group). A decreased efficacy of respiratory muscles in IS patients may explain the lower spirometric volumes, as well as the increased RV [4, 8, 11].

The effect of chest wall strapping on pulmonary elasticity has also been studied in normal subjects [3, 12, 22, 24]. All authors agree that a decrease in lung compliance follows such a thoracic wall restriction. According to our knowledge, the effect of a Boston brace on lung compliance has not been investigated in IS patients. We found, as expected, a significant decrease in $C_{ST(L)}$. Nevertheless, decreased $C_{ST(L)}$ coupled with normal values of $C_{ST(L)}/FRC$, enabled us to conclude that the modification of the elastic lung behavior in IS patients immediately after wearing the Boston brace was due to lung volume reduction and not to any change in airway stability, surface tension, or intrinsic pulmonary elastic properties. According

to our results, the reduction of lung volumes and $C_{ST(L)}$ were not related to the Cobb angle. This finding was in disagreement with a previous report [18], in which Noble-Jamieson et al. found a correlation between VC reduction and Cobb angle after long-term bracing. However, our patients' disease was a "pure" idiopathic scoliosis with a narrow range of Cobb angle, whereas patients who were included in the Noble-Jamieson study suffered from scoliosis of neuromuscular origin.

Our study was designed to assess only the immediate pathophysiological consequences of bracing on pulmonary function. According to recent studies [13, 20], long-term bracing (over a 2-year period) did not harm lung volumes.

We should emphasize that the high degree of correlation observed for all measured lung function parameters – volumes, capacities, and $C_{ST(L)}$ – between the nBB and BB conditions in IS patients make the lung volumes and pulmonary compliance changes predictable and helpful in clinical practice. The indirect effect of the Boston brace on lung elasticity through lung volume reduction shows that simultaneous measurements of $C_{ST(L)}$ and $C_{ST(L)}/FRC$ are necessary for a complete evaluation of pulmonary compliance in IS patients.

Conclusions

The present study has demonstrated that the Boston brace causes an immediate, significant, and uniform reduction in lung volumes in IS patients. Static lung compliance is also reduced, but specific lung compliance remains unaffected. This proves that Boston bracing has an indirect effect on lung elastic behavior, primarily due to the additional external restriction of the thoracic cage, without any actual effect on the elastic properties of the lung. Changes in lung volumes and compliance induced immediately after application of a Boston brace are highly predictable.

References

1. Aubin CA, Dansereau J, De Guise J, Labelle H (1997) Rib cage-spine coupling patterns involved in brace treatment of adolescent idiopathic scoliosis. *Spine* 22:629–635
2. Baydur A, Behrakis PK, Zin W, Jaeger M, Milic EJ (1982) A simple method for assessing the validity of the esophageal balloon technique. *Am Rev Respir Dis* 126:788–791
3. Caro CG, Butler J, DuBois AB (1960) Some effects of restriction of chest cage expansion on pulmonary function in man: an experimental study. *J Clin Invest* 39:573–583
4. Cooper D, Velasquez RJ, Mellins R, Keim H, Mansell A (1984) Respiratory mechanics in adolescents with idiopathic scoliosis. *Am Rev Respir Dis* 130:16–22
5. Day GA, Upadhyay SS, Ho EK, Leong JC, Ip M (1994) Pulmonary functions in congenital scoliosis. *Spine* 19:1027–1031
6. Goldberg CJ, Dowling FE, Hall JE, Emans JB (1993) A statistical comparison between natural history of idiopathic scoliosis and brace treatment in skeletally immature adolescent girls. *Spine* 18:902–908
7. Hibbert ME, Lanigan A, Raven J, Phelan P (1988) Relationship of arm span to height and the prediction of lung function. *Thorax* 43:657–659
8. Jones RS, Kennedy JD, Hasham F, Owen R, Taylor JF (1981) Mechanical inefficiency of the thoracic cage in scoliosis. *Thorax* 36:456–461
9. Kearon C, Viviani GR, Killian KJ (1993) Factors influencing work capacity in adolescent idiopathic scoliosis. *Am Rev Respir Dis* 148:295–303

10. Kennedy JD, Robertson CF, Olinsky A, Dickens DRV, Phelan PD (1987) The pulmonary restrictive effect of bracing in mild idiopathic scoliosis. *Thorax* 42: 959–961
11. Kennedy JD, Robertson CF, Hudson I, Phelan PD (1989) Effect of bracing on respiratory mechanics in mild idiopathic scoliosis. *Thorax* 44: 548–553
12. Klinberg PL, Rehder K, Hyatt RE (1981) Pulmonary mechanics and gas exchange in seated normal men with chest restriction. *J Appl Physiol* 51: 26–32
13. Korovesis P, Filos K, Georgopoulos D (1996) Long term alterations of respiratory function in adolescents wearing a brace for idiopathic scoliosis. *Spine* 21: 1979–1984
14. Leech JA, Ernst P, Rogala EJ, Gurr J, Gordon I, Becklake MR (1985) Cardiorespiratory status in relation to mild deformity in adolescent idiopathic scoliosis. *J Pediatr* 106: 143–149
15. Lonstein JE (1994) Adolescent idiopathic scoliosis. *Lancet* 344: 1407–1412
16. Milic Emili J, Mead J, Turner JM, Glaesek EM (1964) Improved technique for estimating pleural pressure from esophageal balloons. *J Appl Physiol* 19: 207–211
17. Nachemson AL, Peterson LE, and Members of the Brace Study Group of the Scoliosis Research Society (1995) Effectiveness of treatment with a brace in girls who have adolescent idiopathic scoliosis. *J Bone Joint Surg [Am]* 77: 815–822
18. Noble-Jamieson CM, Heckmatt JZ, Dubowitz V, Silverman M (1986) Effects of posture and spinal bracing on respiratory function in neuromuscular disease. *Arch Dis Child* 61: 178–181
19. Olafsson Y, Saraste H, Soderlund V, Hoffsten M (1995) Boston brace in the treatment of idiopathic scoliosis. *J Pediatr Orthop* 15: 524–527
20. Refsum HE, Naess-Andresses CF, Lange JE (1990) Pulmonary function and gas exchange at rest and exercise in adolescent girls with mild idiopathic scoliosis during treatment with Boston thoracic brace. *Spine* 15: 420–423
21. Rowe DE, Bernstein SM, Riddick MF, Adler F, Emans JB, Garder-Bonneau D (1997) A meta-analysis of the efficacy of non-operative treatments for idiopathic scoliosis. *J Bone Joint Surg [Am]* 79: 664–674
22. Scheidt M, Hyatt R, Rehder K (1981) Effects of rib cage or abdominal restriction on lung mechanics. *J Appl Physiol* 51: 1115–1121
23. Sevastikoglou JA, Linderholm H, Lindgren U (1976) Effect of the Milwaukee brace on vital and ventilatory capacity of scoliotic patients. *Acta Orthop Scand* 47: 540–545
24. Sybrecht GW, Garret L, Antonisen NR (1975) Effect of chest strapping on regional lung function. *J Appl Physiol* 39: 707–713
25. Watts HG, Hall JE, Stanish W (1977) The Boston brace system for the treatment of low thoracic and lumbar scoliosis by the use of a girdle without superstructure. *Clin Orthop* 126: 87–92
26. Weber G, Smith JP, Briscoe WA, Friedman SA, King TKC (1975) Pulmonary function in asymptomatic adolescents with idiopathic scoliosis. *Am Rev Respir Dis* 111: 389–397