

Changes of ventilatory parameters in the positional training of persons after cervical spinal cord injury

Zmiany parametrów wentylacyjnych w trakcie pionizacji osób po urazie rdzenia kręgowego w odcinku szyjnym

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Key words

spinal cord injury, spirometry, ventilatory parameters, rehabilitation, postural training

Abstract

Background: Cervical spinal cord injury (CSCI) is followed by mixed respiratory dysfunction.

Purpose: Evaluation of the ventilatory parameters of CSCI patients in postures typical for positional training.

Material: 51 CSCI patients in a mean age of 34.4 (SD=14.6) years; complete motor deficit (CMD) 66.6%; injury of C5 level or above – 68.6%. Control group (CG): 10 healthy volunteers.

Method: Spirometry and flow-volume examination in recumbent (R), sitting (S) and vertical 60° tilt (V) positions.

Main results: Expiratory reserve volume (ERV) undergoes significant positional changes in CG (R: 1.34 L, H: 0.25 L, V: 0.79 L; $p=0.02$), but not in CSCI patients. Transition from R to S in CMD persons results in a significant decrease in vital capacity (VC) (from 2.45 to 1.75 L; $p=0.0008$); inspiratory capacity (IC) (from 2.48 to 1.41 L; $p=0.0008$); forced expiratory volume in 1 second (FEV1) (from 2.21 to 1.64 L; $p=0.002$); forced vital capacity (FVC) (from 2.55 to 1.78 L; $p=0.0004$). The FEV1/FVC rate does not depend on positional changes ranging from 89.7% to 93.9% of the reference values. Ventilatory parameters in the incomplete motor deficit (ICMD) group do not differ significantly between the examined body positions. Transition between R and S in the CMD group results in a significant decrease in the peak expiratory flow (PEF) (from 4.23 to 3.53 L/s) and the peak inspiratory flow (PIF) (from 3.89 to 3.43 L/s), while in ICMD the PEF increases from 4.01 to 4.39 L/s and the PIF increases from 3.66 to 4.18 L/s.

Conclusions: Transition from R to S in CSCI patients results in increased restriction. CMD patients express a reduction of peak flows while in the ICMD peak flows increase after transition between R and S. Shifting from S to a 60° vertical tilt with standard trunk stabilization does not change significantly the ventilatory parameters in CSCI patients.

Słowa kluczowe

uszkodzenie rdzenia kręgowego, spirometria, parametry wentylacyjne, rehabilitacja, trening posturalny

Streszczenie

Założenia: Uraz rdzenia kręgowego w odcinku szyjnym URKOS jest przyczyną złożonych zaburzeń oddechowych o charakterze mieszanym.

Cel: badanie wpływu pozycji ciała stosowanych w treningu pionizacyjnym na parametry wentylacyjne u osób po urazie rdzenia kręgowego w odcinku szyjnym (URKOS).

Materiał: 51 osób po URKOS w wieku średnio 34,4 (sd=14,6) lat (całkowity deficyt ruchowy (CDR) 66,6%, uszkodzenie C5 i wyżej 68,6%); grupa kontrolna (GK): 10 zdrowych ochotników

Metoda: badanie parametrów spirometrycznych i przepływowo-objętościowych w pozycji horyzontalnej (H), siedzącej (S) i w pionizacji 60° (W).

Główne wyniki: Zapasowa objętość wydechowa (ERV) istotnie zmienia się zależnie od pozycji ciała w GK (S: 1,34 L, H: 0,25 L, V: 0,79 L; $p=0,02$) nie ulegając zmianom pozycyjnym w grupie URKOS. U osób z całkowitym deficytem ruchowym (CDR) przy przechodzeniu z H do S znacząco obniża się pojemność życiowa (VC) (z 2,45 do 1,75 L; $p=0,0008$); objętość wdechowa (IC) (z 2,48 do 1,41 L; $p=0,0008$); 1-sekundowa objętość forsownego wydechu (FEV1) (z 2,21 do 1,64 L; $p=0,002$) i natężona pojemność życiowa (FVC) (z 2,55 do 1,78 L; $p=0,0004$). FEV1/FVC w badanych pozycjach utrzymywał się na poziomie 89,7–93,9% wartości należnych. W grupie niecałkowitych deficytów ruchowych (NCDR) nie stwierdzono znamienych pozycyjnych zmian parametrów wentylacyjnych. Przejście z H do S w grupie CDR powoduje znamieny spadek szczytowego przepływu wydechowego (PEF) z 4,23 do 3,53 L/s i wdechowego (PIF) z 3,89 do 3,43 L/s, zaś w NCDR wzrost PEF z 4,01 do 4,39 L/s i PIF z 3,66 do 4,18 L/s.

The individual division on this paper was as follows: A – research work project; B – data collection; C – statistical analysis; D – data interpretation; E – manuscript compilation; F – publication search; G – grant and funding acquisition

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Wnioski: Przejście z pozycji leżącej do siedzącej u osób z URKOS nasila zaburzenia restrykcyjne, w grupie CDR redukuje, zaś w NCDR podwyższa wartość przepływów szczytowych. Zmiana pozycji z siedzącej na spionizowaną do 60° w warunkach standardowej stabilizacji tułowia nie zmienia znacząco parametrów wentylacyjnych osób po URKOS.

INTRODUCTION

As a consequence of cervical spinal cord injury (CSCI) the respiratory system displays restriction and obturator disorders, the intensification of which depend on the nature and localisation of the disorder, the age and weight-height index¹⁻⁶, coexisting deformation of the thorax (e.g. ankylosing spondylitis) and patency impairment of the respiratory tracts (as in chronic obstructive pulmonary disease). Diseases coexisting with the decreased airway diameter have a tendency for decompensation and a characteristic deterioration in the state of health.

Diaphragmatic dysfunction is the most important reason of failure in persons injured above the level of C4, whilst lesions at or below the level of C5 results in failure of the expiratory muscles⁷. A lack of active stabilisation of the thorax, impairment of the coordinated contraction of diaphragm and exterior intercostal muscles, the increased area of adherence between diaphragm and the thoracic wall result in a paradoxical collapse of the thorax during inhalation, decreased respiratory performance and hypoventilation of the upper lung fields⁸. Compensationally during the inspiration phase there occurs an activation of the glossopharyngeal muscles⁹. The rise in respiratory effort in the exhalation phase is a result of increased distensibility of the diaphragm/abdominal muscles unit and a reduction in the compliance of the thoracic wall^{10,11}. In individuals with a complete motor deficit (CMD) following CSCI the effective cough may be attributed to compensatory activation of the clavicular part of the pectoralis major and the latissimus dorsi in the phase of expiration^{12,13}. The contraction of the clavicular part of the pectoralis major is one of the reasons for the paradoxical movement of the abdominal wall when exhaling¹³.

Improvement of the resting breathing pattern with the time elapsing since injury may be ascribed to improvement of accessory respiratory

muscles strength, the appearance of spasticity in the intercostal muscles, improvement in the thorax stability and better circulatory parameters^{8,14}.

A predominance of the parasympathetic nervous system leads to bronchospasm, bronchial hyper-reactivity and mucus overproduction¹⁵. These changes together with a disturbance in the efficacy of expectoration increase the risk of pneumonia significantly decreasing the survival rate after CSCI^{16,17}.

Respiratory exercises consisting of assisted expectoration, drainage positions, resistance strengthening of diaphragm, as well as positional training consisting of the maintaining of a vertical position on a tilt table are inevitable elements of early comprehensive rehabilitation of patients after CSCI. The attainment of adaptation to a sitting position enables locomotion in a wheelchair, improves upper limb function, enables independence in activities of daily living, reduces the risk of complications typical for prolonged recumbency and immobility. In persons with incomplete neural deficit that serves as a starting point for walking training¹⁸.

A change in body position differently influences the ventilatory parameters of individuals with tetraplegia in the course of CSCI and able-bodied individuals^{14,19,20}. The purpose of the study is an analysis of alterations of the spirometric and flow-volume parameters accompanying body positional changes applied in early rehabilitation of individuals with an injured spinal cord.

MATERIAL

51 patients hospitalized in the Rehabilitation Department with a diagnosis of CSCI fulfilling the following criteria:

- achieved adaptation to sitting and vertical positions, i.e. absence of features of orthostatic hypotonia, contractures precluding comfortable and safe sitting position, dis-

turbance in body balance and other psychic or physical discomfort appearing within at least 15 minutes of being seated or tilted to vertical position

- an absence of breathlessness during daily activities,
- negative case history of respiratory disorders, ankylosing spondylitis.

The control group comprised 10 healthy volunteers.

Table 1 presents the characteristics of the studied and control groups.

RESEARCH METHODS

Ventilatory parameters were tested by means of the Lungtest 500 spirometer (produced by MES Ltd) in accordance with the guidelines of the European Respiratory Society²¹. Prior to each series of measurements, the calibration of the equipment on the basis of the surrounding parameters: air temperature, humidity, atmospheric pressure was performed. Tests were conducted on each of the participants in the following body positions: recumbent (R), seated with shoulder-height torso support (S) and vertical (V) on a table tilted up to 60°. Each of the participants was stabilised in the V position by means of non-elastic belts of a width of 20 cm placed at the level of the thorax, the anterior superior iliac spines and by the level of the knees (Fig. 1).

The absolute results and the percentages of the relation to the reference values calculated individually in relation to sex, height, body mass and age were analysed. Through the utilisation of the Shapiro-Wilk Test and χ^2 an absence of features of the normal distribution in the subsets of results developed for comparative analyses was confirmed. Simple regression, Mann-Whitney test and Kuskall-Wallis test were applied in the relevant stages of data analysis.

Table 1

Characteristics of the study and control groups											
Character	Damage level	N	sex		age (yrs)		Smoker	MS		Time since CSCI (Mo)	
			M	F	Mean.	SD		Mean	SD	Mean	SD
CMD	C4-5	20	17	3	34,4	15.4	11 (55%)	14	5.5	9,1	14,3
	C6-8	14	14	0	28,3	7.84	6 (42,8%)	23	9	20,7	37,9
ICMD	C4-5	15	15	0	41,1	16.9	7 (46,6%)	77	19	11,1	7,8
	C6-8	2	1	1	27	9.9	0	83	17	15,5	20,5
Total		51	47	4	34,4	14.7	24 (47,1%)	37	31	10,2	12,4
Control		10	7	3	38,9	11.8	3 (30%)				

M- male, F – female; Mean – average, SD – standard deviation; CMD: complete motor deficite – patients from the group ASIA A and B; ICMD: incomplete motor deficite – patients from the group ASIA C and D; MS –ASIA motor index, CSCI – cervical spinal cord injury; yrs – years; Mo – months



Figure 1
Vertical position on a tilt table. The table is tilted to 60° and the body is stabilized with non-elastic belts at the level of the knees, anterior superior iliac spines and the lower part of the thorax

tween spirometric and flow-volume results and the ASIA motor index. Table 6 compares forced expiratory volume in one second to the forced vital capacity ratio (FEV1/FVC) in smokers and non-smokers comparable regarding muscular strength, the level and completeness of neural deficite as well as values obtained in the control group.

DISCUSSION

The relatively high values of FEV1/FVC ratio obtained in the study group (Table 3) suggest a dominant restrictive constituent of respiratory disurbances in persons after CSCI, which remains in accordance with the observations of Mateus et al². This result should not be attributed to the absence of airway obtruration in patients after CSCI, but rather a de-

Table 2

Mean results of spirometry. In brackets the percentage of the reference values for a sitting position				
Group	Position	VC (L)	IC (L)	ERV (L)
CMD	H	2,45 (48,4%)	2,08 (60,2%)	0,37 (22,5%)
	S	1,75 (34,5%)	1,42 (41,1%)	0,33 (20,8%)
	V	1,76 (34,9%)	1,55 (45,1%)	0,21 (13,4%)
P		0,0004	0,001	0,25
ICMD	H	2,34 (52,2%)	1,93 (65,1%)	0,4 (26,6%)
	S	2,3 (51,7%)	1,86 (63,0%)	0,43 (30,0%)
	V	1,98 (45%)	1,62 (51,6%)	0,44 (31,6%)
P		0,27	0,4	0,76
CSCI in total	H	2,41 (49,7%)	2,03 (61,8%)	0,38 (23,9%)
	S	1,93 (40,3%)	1,57 (48,4 %)	0,37 (23,8%)
	V	1,83 (38,3%)	1,56 (47,3%)	0,29 (18,0%)
P		0,0003	0,002	0,35
Control	H	4,19 (88,1%)	3,64 (103,5%)	0,55 (37,1%)
	S	4,22 (90,1 %)	2,88 (91,8%)	1,34 (90,0%)
	V	3,89 (83,5%)	3,11 (98,2%)	0,79 (53,5%)
P		0,8	0,1	0,02

VC – Vital Capacity; IC – Inspiratory Capacity; ERV – Expiratory Reserve Capacity, H – horizontal position, S – sitting position, V – vertical position, p – significant level in comparison to the tested values in positions H, S and V (Kruskall-Wallis Test)

RESULTS

Averaged results of the spirometry and of the flow-volume tests measured in given body positions are presented by Tables 2 and 3. Table 4 shows the dependence of selected ventilatory parameters measured in the S position on the level and character of the neurological damage. Table 5 illustrates the dependence be-

Table 3

Mean result of flow-volume testing							
Group	P	FEV1 (L)	FVC (L)	FEV1/FVC	PEF (L/s)	PIF (L/s)	MEF 25/75 (L/s)
CMD	R	2,21 (53,3%)	2,56 (51,8%)	87,53	4,23	3,89	2,89 (37,1%)
	S	1,64 (39,5%)	1,78 (36%)	93,88	3,53	3,43	3,21 (39%)
	V	1,58 (38,1%)	1,75 (35,3%)	92,02	3,48	3,3	2,54 (34,6%)
P		0,0002	0,00006	0,00008	0,07	0,25	0,37
ICMD	R	2,03 (55,5%)	2,31 (52,9%)	86,74	4,01	3,66	2,92 (37,3%)
	S	2,0 (55,3%)	2,18 (49,9%)	92,38	4,39	4,18	3,28 (40,4%)
	V	1,8 (49,9%)	1,98 (45,7%)	91,0	3,65	3,6	2,79 (36,4%)
P		0,34	0,19	0,13	0,49	0,42	0,33
CSCI in total	R	2,15 (54,0%)	2,47 (52,2%)	87,27	4,16	3,81	2,86 (36,8%)
	S	1,77 (44,8%)	1,91 (40,6%)	93,38	3,82	3,68	3,23 (39,3%)
	V	1,66 (42,0%)	1,82 (38,8%)	91,68	3,54	3,4	2,57 (35,8%)
P		0,0005	0,00004	0,00006	0,12	0,35	0,37
Control	R	3,33 (86,4%)	4,19 (91,9%)	79,13	7,63	6,57	4,43 (103,4%)
	S	3,42 (89,5%)	4,28 (94,0%)	80,44	7,26	5,97	4,4 (102,4%)
	V	3,22 (84,1%)	3,98 (88,2%)	80,30	6,91	5,15	4,13 (96,4%)
P		0,94	0,75	0,8	0,82	0,49	0,89

In brackets the percentages of the due values for a sedentary position. P: position: R - recumbent, S - sitting; V - vertical; FEV1: Forced expiratory volume in one second; FVC: vital capacity force; PEF: Peak Expiratory Flow; PIF: Peak Inspiratory Flow; MEF 25/75: Mean Expiratory Force between 25 and 75% FVC; p – significant level in comparison to the tested values in positions R, S and V (Kruskal-Wallis Test)

Table 4

Comparison of selected ventilatory parameters between CMD and ICMD patients in relation to the level of injury					
	Level	FVC (L)	FEV1 (L)	PEF (L/s)	ERV (L)
CMD	C4-5	1,32 (27,3%)	1,25 (30,9%)	2,86 (31,6%)	0,29 (18,2%)
	C6-7	2,61 (51,3%)	2,33 (54,8%)	4,58 (48,6%)	0,47 (29,2%)
P		0,00007	0,00006	0,0002	0,43
ICMD	C4-5	2,19 (50,6%)	2,03 (56,4%)	4,16 (48,5%)	0,40 (27,4%)
	C6-7	2,07 (45,4%)	1,85 (47,5%)	6,15 (70,1%)	0,71 (49,1%)
P		0,94	0,94	0,26	0,32

In brackets the percentages of due values, p – the level of statistical significance in the Mann-Whitney Test

creased sensitivity of flow-volume testing resulting from decreased muscular strength in individuals after CSCI in comparison with the able-bodied population^{3,5}. In our research the lack of statistically significant differences of the FEV1/FVC ratio between disabled smokers and non-smokers comparable regarding muscular strength, level and completeness of neural deficits may illustrate decreased test sensitivity in the CSCI population. The FEV1/FVC ratio dif-

ference between smokers and non-smokers to a statistically important degree appeared only in the group of able-bodied individuals (Tab. 6). The degree of FEV1 reduction is not parallel with FVC loss in respect of muscular function loss. The higher level of injury and the lower amount of muscles involved in the exhalation phase, the more significant a reduction of FVC occurs, while FEV1 decreases to a lesser degree. Decrease in expiratory outflow is accompanied

by a lesser degree of airway compression (generating a buoyant resistance) and less turbulent airflow. In the case of slow expiration the air entrapment in airways at the end of the expiratory phase is less evident. The reduction of a baseline airway caliber related to heightened vagomotor tone can persist for a long time after CSCI and may be measured, for example, by means of plethysmography after inhalation of a bronchodilator¹⁵.

A statistically significant dependence between the ASIA motor index and extent of aberrances in the majority of the ventilatory parameters in persons after CSCI was confirmed using linear regression. Spearman coefficients remain at a level of 0,3-0,46 (tab. 5). Many authors have described the dependence between the alterations in ventilatory parameters and the injury level or extent of the motor deficits^{1,16,22}. These relationships may result not only from the influence of particular muscles on the ventilatory pattern (the role of the clavicular part of the pectoralis maior in high tetraplegia should be emphasized¹²), but also of the better chance

Table 5

Linear dependence between spirometric and flow-volume parameters and motor scores (MS) in the study group								
	VC	IC	ERV	FEV1	FVC	FEV1/FVC	PEF	PIF
CC	0,44	0,46	absence	0,35	0,34	absence	0,3	0,3
P	0,001	0,0007		0,01	0,01		0,03	0,03

P - level of statistical significance; CC – Spearman correlation coefficient

Table 6

FEV1/FVC ratio in smokers (S) and non-smokers (NS) representing comparable groups according to the level of injury, character of neural deficit and motor scores (MS)					
		MS mean (SD)	p1	FEV1/FVC mean (SD)	p2
CSCI in total	S	37 (30)	0,5	91,5	0,2
	NS	38 (33)		95	
CMD C6-C8	S	21 (3)	0,8	88,1	0,6
	NS	24 (12)		92,6	
ICMD C4-C5	S	81 (12)	0,9	89,9	0,5
	NS	71 (24)		95	
Control	S	100	1	84,3	0,04
	NS	100		100,5	

mean – average value; SD – standard deviation; p1 – level of significant MS difference; p2 – level of significant FEV1/FVC difference

of ventilatory function regain as a result of aerobic exercises in persons injured at the lower level.

The topography of muscular deficit in CMD following CSCI results in significantly greater disturbances of the exhalation phase compared to the inhalation phase^{2,23}. In the CMD subgroup we found a dependence between the degree of disturbance of the expiratory parameters FVC, FEV1, the maximum expiratory flow (PEF) and the level of injury (Tab. 4). This phenomenon was also described by Mateus², Anke⁷ and Almenoff²³. The correlation between the level of injury and the extent of FVC, FEV1 and PEF disturbances does not exist in the ICMD group (Tab. 4). Retain of any voluntary motion below the injury level is probably responsible for the improvement in the exhalation efficacy. According to Linn⁵ the relation of FVC to the level of injury in individuals with ICMD following CSCI has a prognostic value in regards to the improvement of respiratory efficacy.

The expiratory reserve volume (ERV) is a parameter of particular

significance for an understanding of the pathophysiology of ventilatory pattern in individuals after CSCI. ERV is the maximal volume of air that can be expelled from the lungs after a normal expiration. ERV below 0.6 L indicates a significant weakness of the expiratory muscles²². The reduction in the values of ERV observed in individuals with tetraplegia might be also related to paralysis of the quadratus lumborum muscle innervated from the T12-L3 segments. Synchronisation of the diaphragm contraction with quadratus lumborum prevents the lifting of the 12th rib together with the vertebral part of the diaphragm on inspiration^{7,9}. We found that in the S position both in the ICMD and CMD group the value of ERV is reduced and is independent on the level of neural deficit.

A significant difference between ERV values between the studied body positions was noted in able-bodied individuals ($p=0.02$, Kruskal-Wallis test) (Tab. 2), whereas in the study group ERV remained unchanged in different body positions both in CMD and ICMD.

Baydur²⁴ emphasized a more distinct dependence of ERV on the body position (an increase while seated) amongst individuals with paraplegia in comparison to those with tetraplegia. The insignificant change in vital capacity (VC) and the considerable (approx. 65%) reduction of ERV accompanying transmission from S to R in able-bodied individuals has been confirmed by our observation (Tab. 2). This phenomena may be attributed to the transfer of venous blood to the thorax and the cephalad shift of viscera in a recumbent position²⁵. Persons after CSCI react to body position changes in an opposite way (Tab. 2, 3) displaying an increase in VC (of 9.4% of the predicted values) FVC (of 11.4% of the predicted values) and the absence of changes in ERV. In a supine position the diaphragm increases its inspiratory excursion because its muscle fibres are longer at the end of expiration and operate on more a favourable position of length-tension curve^{19,24}. We suppose that in CSCI, transfer from S to H position is not capable of decreasing significantly the already reduced ERV values observed in position S.

Placing a patient with CDR in a wheelchair (transfer from position H to S) significantly decreases VC from mean values of 2.45 to 1.75 litres (Mann-Whitney test; $p=0.0008$) and the inspiration capacity (IC) from mean values of 2.48 to 1.41 litres ($p=0.0008$) (Tab. 2). We observed significant falls of FEV1 from 2.21 to 1.64 litres ($p=0.002$) and of FVC from 2.56 to 1.78 litres ($p=0.0004$) were observed (Tab. 3). The values of the FEV1/FVC ratio remain stable on body position changes. A further shift from the S to W position did not affected respiratory capacities and peak flows. Individuals with ICMD did not demonstrate any significant alterations of ventilatory parameters on changes in body position. The above observations affirm the conclusions drawn from the research of Maedy²⁰, suggesting that the supine position is the most favourable for the ventilatory mechanism in individuals with tetraplegia. These observations are convergent with the further dependencies considered below. A decrease of ventilatory parameters while seated, beside orthostatic hy-

potension and agrophobia, may have a significant contribution in the limitation of tolerance for a sitting position in early stages of positional training of individuals with CSCI.

Positional changes of PEF and peak inspiratory flow (PIF) depend on the neurological state of studied individuals. A shift from H to S did produce significant alterations of PEF and PIF in the control group. Sitting up from a supine position in individuals with CMD decreased the maximal flows insignificantly. The PEF value fell from 4.23 to 3.53 litres/sec and PIF from 3.89 to 3.43 litres/sec. In the ICMD group a shift from H to S produced an insignificant rise in peak flows: PEF from 4.1 to 4.39 litres/sec, PIF from 3.66 to 4.18 litres/sec. (Tab. 3). Although alterations of absolute values of peak flows did not fulfil criteria of statistical significance, the comparison of the tendencies in each group did produce a significant difference confirmed by the Kruskal Wallis test ($p=0.001$ for PEF and $p=0.002$ for PIF). Ledsome⁶ showed that values of PIF and PEF are related to VC. PIF value depends on the static and dynamic conditions of diaphragm performance, as well as the function of external intercostal and accessory respiratory muscles⁹, while PEF is an effect of abdominal, internal intercostal, serratus anterior, pectoralis maior, latissimus dorsi and is influenced by airway diameter^{12,13}. Increase of peak flows after sitting up in an individual with ICMD possibly results from a better coordination of the work of accessory respiratory muscles while the ERV remains unchanged. In a person with CMD group VC is lower and the abilities to compensate for a decreased respiratory performance are limited. In able-bodied individuals it is likely that the function of the accessory respiratory muscles compensates for ERV positional changes, and it allows one to maintain stable values of peak flows despite changes in body position. Values of peak flows in the control group in the subsequent transition between R, S and V undergo only an insignificant reduction ($p=0.8$ for PEF; $p=0.5$ for PIF; Kruskal Wallis test) (Tab. 3). The above hypothesis requires, however, further research.

Transition between S and V did not produce any significant changes in the studied spirometric and flow-volume parameters in both the control and CSCI groups, what was confirmed with the Mann-Whitney test. Comparison between the subgroups of low and high tetraplegia also did not reveal any significant alterations of the studied values (Tab. 3).

Application of a stabilising belt as in position V (Fig. 1) compresses the abdomen as well as reduces the respiratory mobility of the thorax, limiting a paradoxical thoracic movement typical for a CMD person⁸. Walls and the content of the abdomen may be abnormally compliant in individuals after CSCI because of the abdominal muscle paralysis²⁴. Changes in the ventilator parameters in CSCI persons shifted from S to V should not be therefore interpreted solely as a result of an altered body position, but rather reflect the overall consequences of standard interventions in rehabilitation.

Estenne found that the application of a compression abdominal belt in persons with CMD following CSCI partially compensates for a loss of the abdominal muscle tone improving the expectoration efficacy¹³. Belt application reduces ERV, increases the total lung capacity²⁶ and VC in a sitting position and in 70 degrees of vertical tilt^{27,28}. The pressure exerted by a belt generates some resistance on inspiration, but this effect is sufficiently compensated by elevation of the diaphragm dome at the end of exhalation^{29,30}. A similar effect on the ventilatory parameters of persons with CMD was observed in the immersion in water to shoulder level³¹.

An interesting experiment on individuals with high CMD requiring electrostimulation of the diaphragm was performed by Mead³⁰. One may assume that a pacemaker burst would elicit a recruitment of a similar quantity of motor units on each diaphragm contraction. Application of an abdominal belt in a supine position reduced the tidal volume (TV) by 10 to 20% while in a vertical position on a tilt table the same belt produced TV growth of 200%³⁰ in these individuals.

The absence of significant differences in the ventilatory parameters

after CSCI during the transition from S to V position is of undoubted practical importance, yet the mechanism for this phenomenon is not fully explained. One may suppose that stable spirometric values in the V position result from raised abdominal pressure achieved by the stabilising belt. It is not yet clear to what extent the belt influences the respiratory efficacy by compression of the thorax. The thoracic wall in individuals with chronic disability following CSCI has a lowered distensibility as a result of, among other things, changes in the intercostal muscles²⁴. An answer to this question would require application of other diagnostic techniques including dynamic tensometric measurement in the area of apposition between the belt and the abdominal and thoracic walls.

CONCLUSIONS

1. Spirometric evidence of airway caliber reduction was not found among cervical spinal cord injury subjects who do not express dyspnoea in daily activities.
2. Level of injury corresponds with pulmonary restriction only in those persons after cervical spinal cord injury, who express complete motor deficit.
3. ERV is significantly lower and less susceptible to body positional changes in cervical spinal cord injury subjects when compared to able-bodied individuals.
4. In patients with complete motor deficit, susceptibility of the respiratory system to positional changes increases with the injury level.
5. Transition from recumbent to a sitting position increases restrictive respiratory dysfunction in persons after cervical spinal cord injury.
6. In persons with cervical spinal cord injury transition from recumbent to a sitting position is related to a significant reduction of PIF and PEF in those with complete motor deficit whereas in persons with an incomplete deficit the peak flows increase.
7. Transition from sitting to 60° vertical tilt with trunk stabilisation does not alter significantly the ventilatory parameters of individuals after cervical spinal cord injury.

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