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ORIGINAL ARTICLE

Pulmonary dysfunction in patients after cervical spinal cord injury: serial follow-up measurement within the first year post-injury

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Abstract

OBJECTIVES: Respiratory complications are most common cause of morbidity/mortality in patients with cervical spinal cord injury (cSCI) due to respiratory muscle weakness and lower diaphragm position resulting in limited availability of inspiration, reduced thorax mobility and limited forced expiration. Differences in respiratory dysfunctions (RDs) in patients with motor complete versus incomplete cSCI were assessed.
DESIGN: Prospective longitudinal study, serial measurement.
SETTING: University hospital and ambulatory departments.
METHODS: Twenty two patients with acute cSCI were recruited. Neurological level of injury and severity according to ISNCSCI were used as criteria for recruitment. Patients were divided into two groups – motor complete and incomplete. Standardized pulmonary function tests (PFT) were used – spirometry and respiratory muscle strength (RMS) measurement. Motor score of key muscles assessments for upper (UEMS) and lower (LEMS) limbs were used. Tests were performed in 5 measurement sessions starting on (medians) 14.5 days (M1), then 6.7 weeks, 3.2 months, 6.3 months and 1.0 year (M5).
RESULTS: Significant differences in measurement sessions M2–M5 between groups in forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), expiratory reserve volume (ERV), maximal static inspiratory/expiratory pressures (MIP, MEP) and UEMS were proved. Consequently, prominent differences in courses of particular parameters were found. No intergroup changes in UEMS were found during study.
CONCLUSIONS: Obvious differences in parameters of spirometry, respiratory muscles and limb muscles strength between motor complete and incomplete group were found. Carefull monitoring of RDs by functional assessments (i.e., PFT and UEMS/LEMS tests) within one year after SCI seems to be clinically important.

Abbreviations:

PFT	- pulmonary function tests
FVC	- forced vital capacity
FEV1	- forced expiratory volume in 1 second
UEMS	- upper extremity motor score
LEMS	- lower extremity motor score
ERV	- expiratory reserve volume
RDs	- respiratory dysfunctions
SCI	- spinal cord injury
cSCI	- cervical spinal cord injury
ISNCSCI	- International Standards for Neurological Classification of Spinal Cord Injury
MIP	- maximal inspiratory pressure
MEP	- maximal expiratory pressure
TLC	- total lung capacity

INTRODUCTION

Respiratory complications are leading cause of morbidity and mortality in patients with cervical spinal cord lesions (cSCI) within the first year post-injury (Brown *et al.* 2006; Cardozo 2007). Tidal breathing pattern is usually ensured only through the diaphragm or eventually through accessory inspiratory muscles. A reduced ability to perform a proper tidal inspiration is due to lower diaphragm position with a low intra-abdominal pressure (Baydur *et al.* 2001). Concomitant paralysis of the intercostal muscles also reduces the mobility of the chest. Moreover, a loss of active support of the abdominal wall represents a major limitation of forced and rapid expiration. Therefore, these conditions make a proper expectoration impossible and patients are in a high risk of development of atelectasis and bronchopneumonia (Galeiras Vázquez *et al.* 2013; Schilero *et al.* 2009; Tamplin & Berlowitz 2014).

The results of pulmonary function tests (PFT) can depict both respiratory dysfunction itself and its development. Careful monitoring of PFT indices may detect functional deviations of the respiratory system before they become clinically significant. There were mostly retrospective and/or cross-sectional studies within last 15 years that brought a meaningful contribution to the general knowledge on pulmonary dysfunction after SCI (Baydur *et al.* 2001; Brown *et al.* 2006; Kelley *et al.* 2003; Postma *et al.* 2009; van Silfhout *et al.* 2016). Many of the studies, especially the older ones, have used insufficient SCI neurological classification (ISNCSCI classification absent) or methodological limitations (use of just basic spirometric parameters, missing information of age of injury, etc.). Pulmonary rehabilitation, and particularly respiratory physiotherapy (Px) represent an effective tool to improve respiratory dysfunction (Galeiras Vázquez *et al.* 2013; Postma *et al.* 2014; Postma *et al.* 2013). An effect of Px on respiratory system is easily assessed using PFT methods (Kang *et al.* 2006).

The aim of the present prospective longitudinal study using three standardized PFT methods is to assess respiratory dysfunctions in identical patients within the first year after cervical SCI. We compared the difference in the development of respiratory dysfunctions in a group of motor-complete and motor-incomplete cSCI.

Tab. 1. Patients' characteristics.

		Motor complete		Motor incomplete		
		mean	SD	mean	SD	*p*-value
Age	[years]	35.1	15.9	47.8	15.6	NS
		N	%	N	%	
Gender	Male	7	63.6	9	81.8	NS
	Female	4	36.4	2	18.2	
Cause	Falls	3	27.3	7	63.6	NS
	Traffic accidents	2	18.2	2	18.2	
	Jumps into water	5	45.5	1	9.1	
	Skiing	0	0.0	1	9.1	
	Myelitis	1	9.1	0	0.0	
NLI	C3	1	9.1	3	27.3	NS
	C4	7	63.6	5	45.5	
	C5	0	0.0	2	18.2	
	C6	1	9.1	0	0.0	
	C7	2	18.2	0	0.0	
	C8	0	0.0	1	9.1	
Total		**11**	**100.0**	**11**	**100.0**	

(NS – not significant)

PATIENTS AND METHODS

Twenty two patients with an acute cervical spinal cord lesion (cSCI) were recruited (16 men/6 women). The leading cause of cSCI in our group (of 22 patients) were the falls, followed by traffic accidents and jumps in the shallow water. The average age at the time of cSCI was 41.5±16.7 (median 36.5) years. The patients were divided after the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) criteria into the group of motor complete (AIS A, B, N=11) and group of motor incomplete (AIS C, D, N=11) lesions (Table 1). The main recruitment criterion was the neurological level of injury (cSCI) and severity of injury according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI). The neurological level of the cSCI was defined based on an evaluation of motor level of preserved function of key muscles and sensory level according to preserved sensitivity in the key sensory points. ASIA Impairment Scale (AIS) was used for an assessment of severity of the cSCI. Therefore, AIS A represents a sensorimotor complete lesion, AIS B indicates a motor complete, sensory incomplete lesion. Both AIS C as well as AIS D indicates a motor incomplete lesion. During the study period (i.e. up to 12 months post-injury), we assessed possible improvement in motor functions according to the motor score. Therefore a motor score for the upper limbs (i.e. upper extremity motor score, UEMS) and a lower extremity motor score (LEMS) is determined by a muscle strength of five key muscles on upper and lower limbs respectively. The study protocol was approved by local ethical committee of University Hospital Motol and all subjects have signed informed consent.

All measurements were performed on the following time intervals from the date of SCI: first measurement (M1) on 14.5 (median), 15±7 (mean±SD) days, M2 on 6.7 (7.0±1.2) weeks, M3 on 3.2 (3.3±0.3) months, M4 on 6.3 (6.7±1.1) months and M5 on 1.0 (1.1±0.3) year, respectively. PFT data were performed using a portable spirometer MasterScope VIASYS, Care Fusion, USA. Spirometer was technically adapted and arranged as the bed-side device. All measures were performed meeting the American Thoracic Society/European Respiratory Society (ATS/ERS) standards and the spirometer was calibrated every day according to the ATS/ERS guidelines (Miller *et al.* 2005). Patients were studied between 10 AM and 2 PM. Our subjects were tested in semirecumbent (45°) position (in the first three measurements). The M4 and M5 measurements were performed in seated position. Note that the standard treatment protocol of the Spinal Cord Unit (University Hospital Motol) was held during hospitalisation. However, no medication possibly affecting airway tone and/or calibre was given to our subjects prior to measurements.

The following PFT data were recorded consecutively in every measurement session: first, vital capacity (VC_{IN},VC_{EX}) and expiratory reserve volume (ERV) were obtained. Consecutively, maximum expiratory flow-volume curves were performed in order to obtain the values of forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1). At least 3 reproducible tests were performed in every session at a pause of 1 minute. No excessive back-extrapolation of FVC was required (Kelley *et al.* 2003). The best value of every particular parameter was selected as the result. These results were compared with reference values from the European Community for Steel and Coal (Quanjer *et al.* 1993).

For the respiratory muscle function the maximal static inspiratory (MIP) and maximal static expiratory (MEP) tests were performed. These measurements were performed using the Respiratory Muscle Strength (RMS) module (manufactured by the same company) connected tightly to the spirometer prior to calibration and all measurements. First, from tidal breathing the patient slowly exhaled as deeply as possible. The operator urged the subject to inspire from the near RV level as fast and powerful as possible against the closed electronically driven shutter valve (Mueller maneuver). Second, similarly, from tidal breathing the patient slowly breathed in as deeply as possible. The operator urged the subject to expire from the TLC level as fast and powerful as possible against the closed shutter valve (Valsalva maneuver). At least 3 acceptable tests for MIP as well as MEP values were performed in every session at pause of 1 minute. The MIP as well as MEP had to be reached after about 0.5–1 second. Then the pressure plateau of minimally 1 second was held as a rule for acceptable test. All these measures met the proper standards (Gibson *et al.* 2002).

Statistical analysis has been carried out in Dell Statistica (Dell, USA), version 13 (2015). Continuous numeric parameters were visually checked for normality and are reported as percent of predicted values. Descriptive statistics is provided as mean±standard deviation (S.D.) in text and mean±standard error of the mean (S.E.M.) in figures. Repeated measurements were intra and extrapolated where necessary (Bluechardt *et al.* 1992) and ANOVA for repeated measurements with Fisher post-hoc test were used for testing of differences between groups and among measurement sessions (M1–M5). Level of statistical significance was set to 0.05.

RESULTS

First, intergroup changes in particular spirometric (Table 2) as well as respiratory muscle strength (Table 3) parameters were shown. Statistical differences between groups are shown in the bottom row of every particular Table. Second, a dynamics of successive changes in these particular variables is also shown (i.e. changes among particular measurements within every Group). For statistical differences within every group – see particular comments.

Spirometry

We proved significant differences in vital capacities (parameters of FVC, VC_{IN} as well as VC_{EX}) and FEV_1 between motor complete and incomplete groups in measurements M2–M5 ($p<0.05$). There was significant correlation between vital capacities (r=0.99, $p<0.001$), so only FVC is reported. Vital capacities (FVC, VC_{IN}, VC_{EX}) showed gradual increase from M1 to M5 ($p<0.05$, see Figure 1). FEV_1 showed different pattern of increase in that there was delayed improvement in motor complete group (M3 to M5) but there was earlier significant improvement in motor incomplete group (M1 to M3, see Figure 2).

A different course of a development of expiratory reserve volume (ERV) after SCI was found between both groups in measurements M2–M5 (see Figure 3). While a significant ($p<0.05$) stepwise increase of ERV in motor incomplete group was found from M1 to M5, the increase in motor complete group was limited to the last measurement (M5 different from M1–M4, $p<0.05$).

A different course of a development of ERV (% predicted) to VC (% predicted) ratio (ERV/VC) was found between both groups in measurements M3–M5 (see Figure 4). A significant ($p<0.05$) difference of ERV/VC in motor complete group was found from M1 to

Tab. 2. Spirometry (% predicted).

	M1	M2	M3	M4	M5
FVC					
complete	48.4±9	53.4±8.8	54.7±9.4	63.9±13.3	68.0±15.7
incomplete	59.3±16.7	71.2±18.2	82.5±13.5	84.7±11.0	87.9±14.0
p-value	0.135	0.001	0.001	0.003	0.004
FEV1					
complete	48.6±11.4	49.6±12.8	53.8±13.7	62.2±17.3	68.8±18.7
incomplete	60.2±17.3	72.4±19.8	82.4±17.6	85.6±15.2	88.9±19.4
p-value	0.266	0.002	0.002	0.007	0.015
ERV					
complete	38.3±21.0	44.8±23.6	49.6±25.6	62.3±28.9	73.2±29.7
incomplete	61.0±50.6	75.9±55.6	104.5±39.7	121.2±35.5	148.0±69.6
p-value	0.400	0.033	0.004	0.004	0.001
ERV/VC					
complete	0.679±0.372	0.804±0.439	0.837±0.417	0.980±0.356	1.112±0.414
incomplete	0.795±0.645	1.113±0.648	1.276±0.350	1.485±0.339	1.650±0.530
p-value	0.606	0.064	0.018	0.017	0.014

Tab. 3. Respiratory muscle strength (% predicted).

	M1	M2	M3	M4	M5
MIP					
complete	47.8±16.8	47.8±19.1	54.2±21.5	58.3±24.6	60.2±26.6
incomplete	59.0±19.6	69.4±20.3	83.2±17.7	87.0±22.4	98.7±21.4
p-value	0.349	0.008	0.005	0.003	0.003
MEP					
complete	34.0±8.7	34.2±11.9	34.3±12.1	35.5±10.2	37.4±9.2
incomplete	47.5±20.1	45.9±21.9	58.2±17.4	64.3±20.8	66.8±20.3
p-value	0.043	0.020	0.002	0.002	0.001

M3 (compared to M5). A significant ($p<0.05$) stepwise increase of ERV/VC in motor incomplete group was found (namely M1 from M3–M5, M2 from M4–M5 and M3 from M1 and from M5, respectively). Note that motor complete group crossed the "line of proportionality" (ERV/VC ratio=1.0) between M4 and M5, however in motor incomplete group it occurred already between M1 and M2.

Respiratory muscle strength (RMS)

A successive stepwise increase of mean values of maximal inspiratory pressure (MIP) was found in earlier (from M1 to M3) in motor incomplete group and later (from M4 to M5) in motor complete group ($p<0.05$). There was difference between groups from M2 to M5 ($p<0.01$).

Regarding maximal expiratory pressure (MEP) there was significant ($p<0.05$) difference between groups in all measurements (M1 to M5, see Figure 6). There was no change in MEP in motor complete group among measurements. Contrary to that motor incomplete group showed increase of MEP from M2 to M4 ($p<0.05$).

Muscle strength of upper and lower extremities

We proved a stepwise increase of upper extremity motor score (UEMS) from M2 to M4 in motor incomplete group ($p<0.01$). It means there was a significant difference between M1–M2 and M4–M5 ($p<0.05$). Despite UEMS of motor incomplete group was higher in M3 to M5 no differences between both groups in these particular sessions were proved (see Figure 7).

Testing of dynamics of lower extremity motor score (LEMS) showed different pattern of changes. There were significant differences in all the measurements between groups ($p<0.001$). No intragroup changes among particular measurements were proved in motor

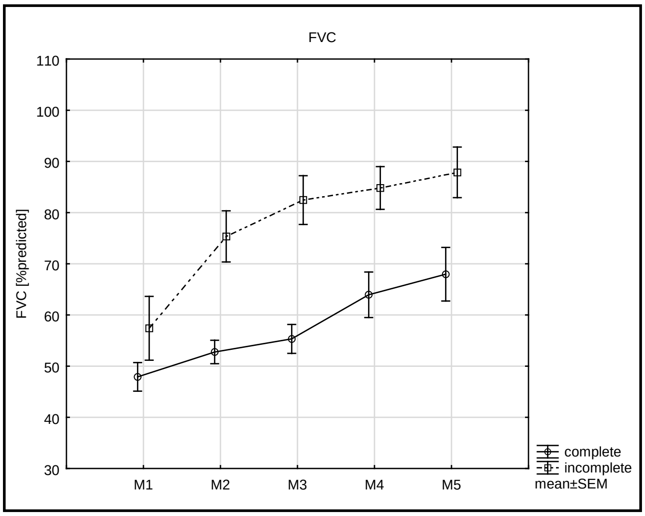

Fig. 1. FVC (% predicted) in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 2.

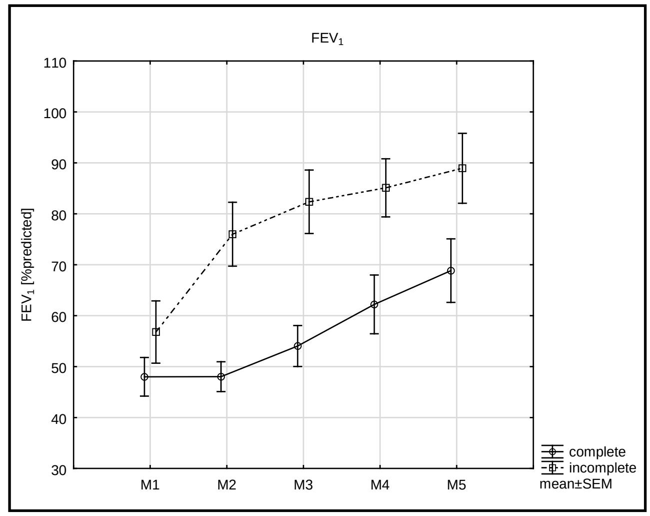

Fig. 2. FEV_1 (% predicted) in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 2.

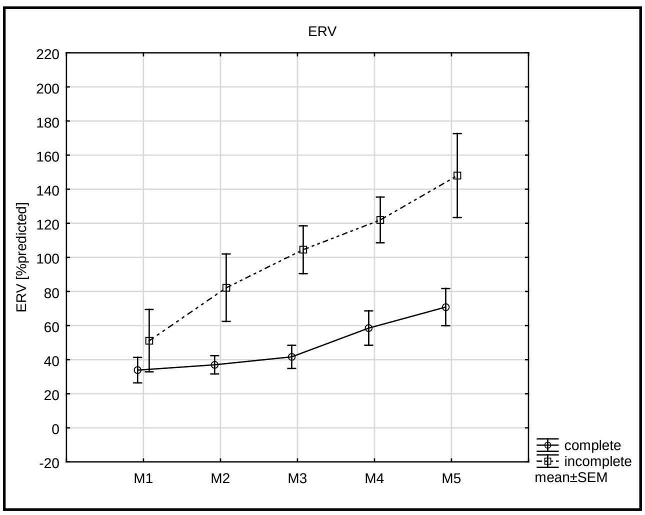

Fig. 3. ERV (% predicted) in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 2.

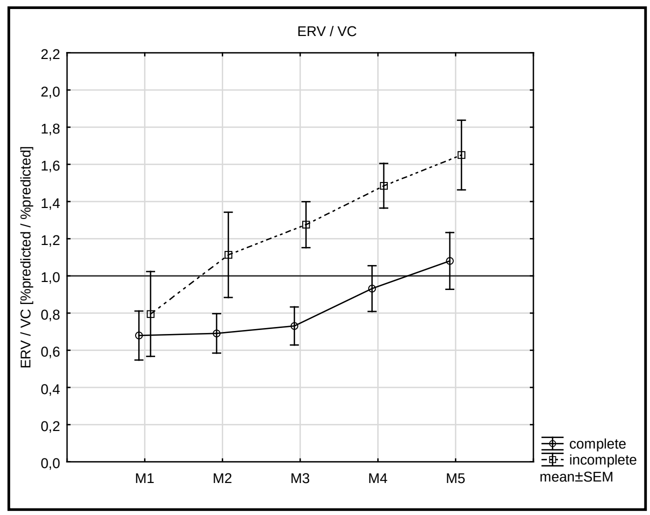

Fig. 4. ERV/VC ratio (% predicted / % predicted) in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 2.

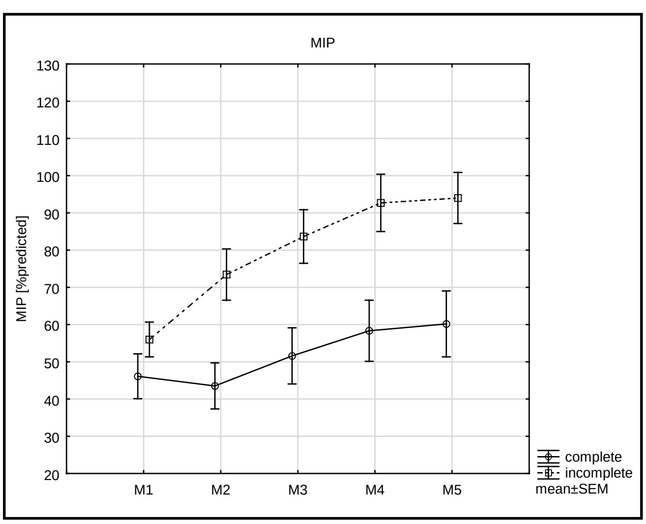

Fig. 5. MIP (% predicted) in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 3.

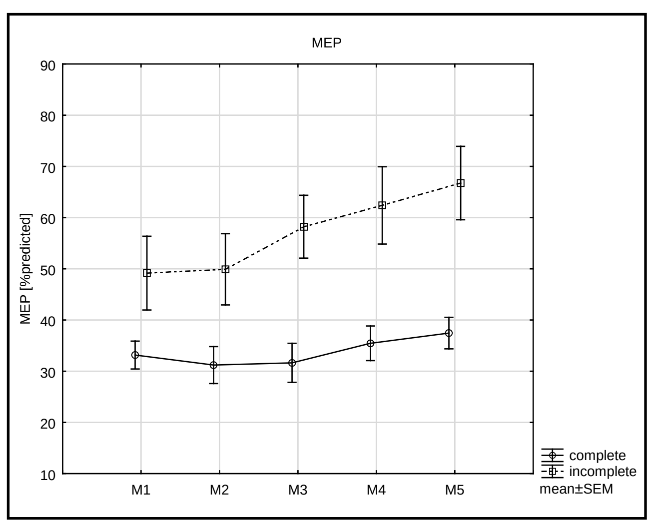

Fig. 6. MEP (% predicted) in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 3.

complete group. Significant differences were found only between M1 and all resting measurements as well as between M2 and all resting measurements. No other intragroup differences were found (see Figure 8).

DISCUSSION

When comparing the results of spirometry in patients with motor complete and motor incomplete cSCI within one year post-injury we noted difference in PFT parameters between groups and different dynamics of particular PFT parameters development. Stepwise increase of forced vital capacity (FVC) in both our groups was found but significant FVC differences between the groups were found in second and later measurements (M2–M5). While in motor incomplete cSCI group there was the most prominent increase between M1–M2 and M2–M3 (i.e. in 3 months post-injury), the motor complete cSCI group revealed the most prominent difference between M3–M4 (i.e. after third month post-injury). Similar changes (compared to FVC) in parameter of FEV1 were found in motor incomplete group. However, in motor complete group we found just minimal (i.e. non-significant) changes between M1 and M2.

To explain these intergroup findings we have to suggest several factors which might play a role. Patients with motor incomplete cervical lesions during their hospitalization in the Spinal Cord Unit (University Hospital Motol) were rigorously observed during the first 2–3 months post-injury. During this period, we found significant improvement in the lower extremities muscle strength (LEMS, Table 4). It coincides also with an improvement of trunk muscle activity. In this context, trunk muscle activity is quite important for FEV1 performance. As demonstrated in study of Langbein *et al.* superficial electrical stimulation of the abdominal muscles significantly improved only a parameter FEV1 (its increase ranged from 46 to 93% of initial values) but FVC increased only up to 22% of initial values (Langbein *et al.* 2001). Another important factor may be early initiation of verticalization into a sitting position, or even standing up in incomplete cSCI. Therefore, we consider early verticalization along with improvement of physical fitness as the main factors affecting a successful and early improvement of both dynamic lung volumes and LEMS between M1 and M2, and/or M3, respectively.

Patients with motor complete cSCI have a significantly different post-injury course. Due to the loss of

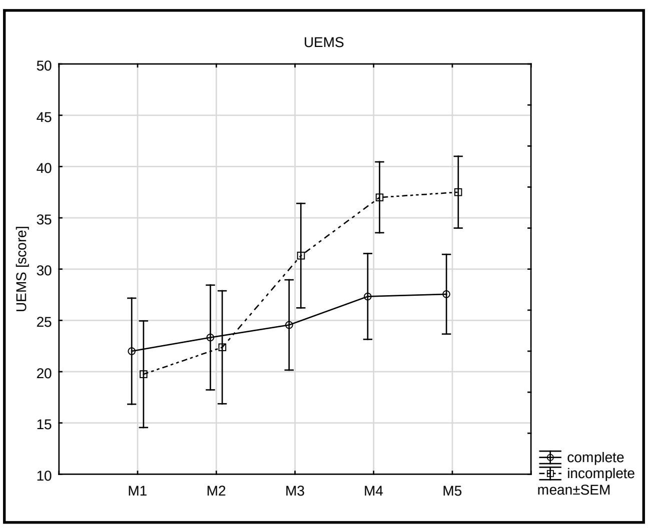

Fig. 7. UEMS in complete (solid line) and incomplete (dashed line) group, differences between groups shown in Table 4.

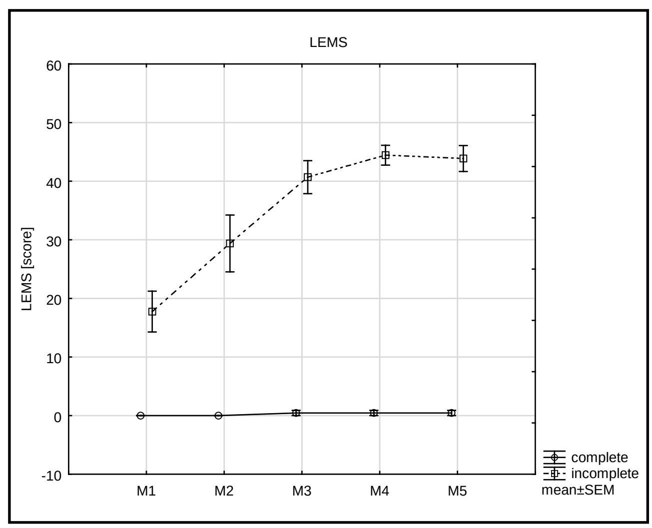

Fig. 8. LEMS in complete (solid line) and incomplete (dashed line) group.

Tab. 4. Upper and lower extremities motor scores.

	M1	M2	M3	M4	M5
UEMS					
complete	21.2±14.0	22.8±13.9	24.2±11.9	27.3±12.5	27.6±11.7
incomplete	20.7±14.2	23.0±16.6	31.3±14.4	38.0±9.6	37.5±9.9
p-value	0.735	0.885	0.315	0.156	0.146
LEMS					
incomplete	20.5±10.8	30.1±14.6	40.7±8.0	45.1±4.8	43.9±6.3

sympathetic tone they suffer from resting and orthostatic hypotension, which within the first 2–3 months significantly limits whole process of rehabilitation (especially a verticalization) (Krassioukov *et al.* 2009). Therefore, the motor complete cSCI patients exhibit delayed functional improvement compared to motor incomplete group. Moreover, an initial stagnation of FEV1 can be related to a post-injury parasympathetic predominance resulting in an increased airway muscle tone and bronchial hyperactivity (Baydur *et al.* 2001). Due to a quite simple FEV1 definition and reproducibility even in cSCI patients using modified criteria for acceptability (Kelley *et al.* 2003) we suggest a parameter of FEV1 as a proper index of an expectoration ability. In agreement with other authors (Baydur *et al.* 2001; Brown *et al.* 2006; Galeiras Vázquez *et al.* 2013; Kelley *et al.* 2003; Postma *et al.* 2009; Postma *et al.* 2014; Postma *et al.* 2013; van Silfhout *et al.* 2016) we confirmed successive increase of the dynamic lung volumes (both FVC and FEV1) in patients within the first months after SCI. FVC (as the most frequently used parameter in these studies) represents the most important index of pulmonary function, which correlates significantly with both FEV1, but also with static PFT parameters such as ERV, FRC, RV, TLC and their ratios (Haas *et al.* 1985). A proper knowledge of interpretative strategy in FVC changes should allow resolution between lung volume restriction (in which both FVC and TLC reduction appears) and lung dynamic/static hyperinflation (in which a negative correlation between FVC and RV /TLC occurs).

To assess possible redistribution of static lung volumes in our groups after acute SCI, we focused on the development of the expiratory reserve volume (ERV) within one year post-injury. While in motor incomplete group we found a successive increase from M1 to M5, the motor complete group revealed substantial, significant growth just since M3. These findings in intergroup differences are almost similar compared to dynamics of FVC, FEV1 as well as, in part, even MEP and UEMS parameters (see Figures 1–3, 5–6).

It is important to stress that a simple increase in the ERV (despite varying intergroup dynamics of this parameter) does not reflect only a stepwise progression of lung hyperinflation. Very similar pattern of FVC dynamics (see Figure 1) indicates that a stepwise increase of VC (and probably the whole lung size according to a value of TLC, too (Baydur *et al.* 2001; Haas *et al.* 1985)) has an important effect on ERV growth. To assess this suggestion we deal with a development of ERV/VC ratio (see Figure 4). We plotted in this Figure on Y axis a solid line valued of 1.0 (i.e. when % ERV equals % VC) to differentiate possible presence of successive increase of either lung size or lung hyperinflation. Indeed, we found quite different dynamics of courses in both groups: the motor complete group showed late changes between 6 and 12 months post-injury in spite of convincing early changes of ERV/VC ratio in the incomplete group. To depict this finding we suggest that it reflects a favorable increase in VC in the complete group compared to even full normalization of VC in incomplete group (VC reached 88% predicted by the end of study). However, a presence of dynamic (i.e. not static) lung hyperinflation in incomplete group cannot be excluded.

We distinguish some different course between both groups in the parameter of maximum inspiratory pressure (MIP). As described above, the resulting MIP values depend on the patient's ability to perform Mueller maneuver. Despite a standardly applied excessive encouragement (i.e. operator´s massive coaching during PFT testing) all our cSCI patients had substantial limitations in MIP performance. As tidal breathing is ensured predominantly by a diaphragm itself, proper performance of Mueller maneuver in cSCI subjects has to be ensured both by diaphragm and gradually involved (during the post-injury period) accessory inspiratory muscles. Generally, an ability to perform correct breathing pattern and the forced inspiration (Mueller maneuver) is significantly limited in patients with acute cSCI by muscle weakness, paradoxical chest movement and disadvantageous (i.e. low) diaphragm position as well as by low intra-abdominal pressure (Baydur *et al.* 2001; Scanlon *et al.* 1989). Due to successive improvement of these conditions there is gradual increase of MIP in motor incomplete group within one year after injury from 59% (M1) to even 99% (M5) of predicted value (Figure 5). Contrary, MIP in the motor complete group increased from 48% (M1) to only 60% (M5). Moreover, a different MIP intergroup dynamics was found. While motor incomplete group showed a successive increase in MIP, complete group revealed insignificant transient stagnation of MIP between M1 and M2 (Figure 5). For explanation, a course in motor incomplete group corresponds to a gradual improvement in motor activity, then verticalization, specific physiotherapeutic techniques etc. Another point: as described in Methods, first, semirecumbent (for M1–M3) and, second, sitting position (for M4 and M5) were used for study sessions measurements. Those condition in motor complete cSCI might be associated with stagnation in two initial examinations due to these patients could perform better motor outcome of accessory inspiratory muscles during M4 and M5 sessions. For these reasons MIP is the only parameter which may also reflect changes in motor score of the upper limbs (UEMS).

We found different values and different courses in parameter MEP between both groups. In motor incomplete cSCI a continuous successive increase of this parameter occurred, as it ranged from 48 to 67% predicted. In contrast, the MEP value in motor complete group reached throughout the study only 34–37% predicted (Figures 5 and 6, Table 3). Dynamics of MEP changes in motor incomplete group coincides with a gradual improvement in strength of intercostal muscles along with successive recruitment of abdominal and pelvic muscles as they represent a stepwise improvement of trunk support (required for a proper performance of MEP maneuver). The initial stagnation between M1 and M2 can be explained by poor neuromuscular coordination, which is also required for a proper performance of forced Valsalva maneuver (despite increase of strength of the involved muscle groups, including upper extremities). Subsequently, a later gradual improvement of MEP parameter might be a reflection of the post-injury physiotherapeutic re-education of proper muscles recruitment and also due to better coordination required for a proper forced expiratory maneuver stereotype. Significant relationship between respiratory muscle strength and dynamic lung volumes (FEV1 and FVC) was observed only in motor incomplete group with the lowest values of MIP (Stolzmann *et al.* 2008). Dynamics of MEP changes in motor complete group coincides with persistent plegia of intercostal muscles, which also negatively affects the mobility and elasticity of the chest (Baydur *et al.* 2001; Scanlon *et al.* 1989). Additionally, the loss of active support of the abdominal wall represents a major limitation of forced and rapid expiration. Therefore, motor complete group persists for at least one year after the injury in condition of limited exhalation. This finding explains the inability to make adequate expectoration (Jeong & Yoo 2015; Kang *et al.* 2006; McCaughey *et al.* 2015; Postma *et al.* 2016; Postma *et al.* 2015; Prevost *et al.* 2015; Walter *et al.* 2015). Any respiratory infection can be more severe, due to a poor ability to expectorate often leads to the development of atelectasis and bronchopneumonia (Brown *et al.* 2006; Cardozo 2007). Surprisingly, just one sporadic paper (Stolzmann *et al.* 2008) suggests long-term decline (approximately 32 years after SCI) of FVC, which is not directly related to a level and severity of SCI. Author proposed potentially modifiable factors, such as age at injury, increasing BMI development, unsuccessful smoking cessation, poor management of possible wheezing and a poor respiratory muscles training. Similarly, an analysis of a random coefficient in a multicenter prospective cohort study of 180 chronic SCI patients (complete versus incomplete SCI) showed three different ways of changes in parameter of FVC during the 5 years after SCI: 1) Improvement 2) no change 3) deterioration in values of FVC values (Postma *et al.* 2013). This author and her Dutch team report important variables that could significantly affect the long-term results (i.e. over 5 years): higher body mass index, inadequate training of the respiratory muscles, and especially poor physical fitness.

In this context, we recommend not only standard careful and long-term follow-up of patient after acute, sub-acute as well as chronic SCI and their current condition (such as lifestyle, bad habits, inadequate weight gain, persistence in rehabilitation and proper muscle training etc.) but also very ordinary and careful check of patient's clinical condition. This monitoring should include a careful and well-informed monitoring of high-risk clinical condition such as risky recurrent atelectasis, pneumonia and possible respiratory failure (Brown *et al.* 2006; Cardozo 2007; Galeiras Vázquez *et al.* 2013; Schilero *et al.* 2009; Tamplin & Berlowitz 2014). This is a task of future studies, in which probably, their authors will probably discover other, yet unknown risks of long-lasting development of respiratory system dysfunction after SCI as it might be life threatening.

In conclusion, we found gradual improvement in dynamic lung volumes and respiratory muscle strength that was generally lower and delayed in complete SCI. The forced parameters, especially FEV1, tend to increase with longer delay in complete SCI possibly due to delayed improvement in coordination of accessory expiratory muscles. As these changes were carefully monitored within one year after SCI we suggest an importance of such monitoring by PFT and functional assessments, which might detect the respiratory system dysfunctions before they become clinically significant. Present data on spirometry, respiratory muscle strength and extremities motor score assessed serially within one year post-injury bring new insight on differences in clinical conditions between motor complete and incomplete cSCI.

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