J Musculoskelet Neuronal Interact 2024; 24(4):361-369

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

Respiratory Muscle Strength Correlation with Functional Capacity, Quality of Life, Demographics and Co-morbidities in Stroke and Spinal Cord Injury

Sofia Ferfeli[1], Antonios Galanos[2], Ismene A. Dontas[2], Dimitrios Pitidis-Poutous[3], Ioannis K. Triantafyllopoulos[4], Zaira Symeonidou[5], Damiani Tsiamasfirou[1], Efstathios Chronopoulos[2]

[1] 2nd Physical Medicine and Rehabilitation Clinic, National Rehabilitation Centre, Ilion, Greece;
[2] Laboratory for Research of the Musculoskeletal System, School of Medicine, National and Kapodistrian University of Athens, KAT Hospital, Athens, Greece;
[3] Department of Neurology, Evangelismos General Hospital, Athens, Greece;
[4] HYGEIA Private Hospital, Athens, Greece;
[5] Department of Physical and Rehabilitation Medicine, 414 Military Hospital of Special Diseases, Penteli, Greece

Abstract

Objectives: To record Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) in neuro-rehabilitation patients and establish correlation with functional status, quality of life, demographics and co-morbidities. **Methods**: Respiratory muscle strength was measured in 50 stroke patients and 50 spinal cord injury (SCI) patients. Both groups were evaluated with the Modified Barthel Index (MBI-Shah version) and the 36-Item Short Form Survey. Demographics, medical history, history of moderate physical activity prior to injury and American Spinal Injury Association (ASIA) classification were recorded. **Results**: Respiratory muscle strength declined with age and males exhibited higher MIP and MEP in the SCI group and higher MEP, but not MIP, in stroke. In the ASIA D SCI subgroup, the MBI total score was moderately positively correlated with MIP and MEP values. In stroke, MBI total score and MEP were positively correlated in both sexes and MBI total score and MIP in females. Diabetes mellitus absence correlated with higher MIP and MEP in SCI. Prior physical activity was linked to higher MIP, MEP in stroke and to higher MIP in SCI. **Conclusions**: Age, sex, functional capacity, SCI classification, quality of life components, history of physical activity and diabetes influence respiratory muscle strength in the studied population.

Keywords: Maximal Expiratory Pressure, Stroke, Maximal Inspiratory Pressure, Modified Barthel Index, Spinal Cord Injury

Introduction

Respiratory muscle strength assessment at the mouth, as measured by the recording of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP), is used for respiratory muscle weakness diagnosis and follow-up of patients with various neuromuscular diseases, among which stroke and Spinal Cord Injury (SCI)[1]. Other conditions include myasthenia gravis, muscular dystrophy, Guillain Barré syndrome, amyotrophic lateral sclerosis, poliomyelitis, spastic or flaccid tetraplegia of any origin, sarcoidosis and polymyositis[1,2], with application in decision-making when weaning from mechanical ventilation[3]. Since lung volume doesn't change significantly during MIP and MEP measurement, the results are considered to reflect respiratory muscle strength, uninfluenced by lung tissue properties[1,2,4].

Maximal Inspiratory Pressure, also known as Negative Inspiratory Force (NIF), reflects the maximal negative pressure achieved when inspiration starts at functional

The authors have no conflict of interest.

Corresponding author: Sofia Ferfeli, 2nd Physical Medicine and Rehabilitation Clinic, National Rehabilitation Centre, 1 Sp. Theologou Street, 13122, Ilion, Greece
E-mail: sfougia@hotmail.com

Edited by: G. Lyritis
Accepted 25 June 2024

residual capacity volume, against a blocked mouthpiece[1]. It is considered a non-invasive, independent diagnostic tool, since it represents inspiratory muscle neuromuscular function and strength, especially pertaining to the diaphragm[1]. Diaphragm weakness is linked to dyspnea and nocturnal hypoventilation, resulting in impaired rapid eye movement sleep phase, fatigue and somnolence during daytime, and morning headaches[5]. Thus, inspiratory muscle weakness has a direct effect on patients' performance in Activities of Daily Living (ADL) and their quality of life[5].

Maximal Expiratory Pressure is measured with the individual performing an active maximal expiratory effort, starting from total lung capacity volume, with a sealed glottis. This positive pressure reflects the strength and neuromuscular function of expiratory muscles, including internal intercostals, external and internal oblique abdominals and rectus and transverse abdominis muscles[2,4]. Weakness of the above muscles leads to inadequate cough production and lung secretion clearance, and in conjunction with possible swallowing disorders, it is an important risk factor for respiration pneumonia[1].

Maximal static respiratory pressures have been recorded to alter in SCI patients, presenting a linear regression based on neurological level of injury (NLI), estimated by American Spinal Injury Association (ASIA) guidelines[6,7]. More specifically, significant correlation has been established for complete motor lesion levels (ASIA A, B), that is when no motor function is preserved below the NLI, and the correlation for MEP is stronger than for MIP[6,7]. The diaphragm, the main inspiratory muscle, receives its innervation from cervical nerves C3-C5 and thus, SCI patients with those levels of injury present with the lowest MIP values, while in patients with a NLI below thoracic (T) 1 level, normal MIP values are recorded[6]. On the other hand, the abdominal muscles, mostly recruited for expiration, are innervated from T6-T12 nerves, which explains the greater negative influence SCI has on MEP values in these individuals as well as the better correlation established with the NLI[6,8].

Decreased MIP and MEP values, which are lower than would be expected due to lean muscle mass or muscle strength loss based on age progression alone, have also been observed in stroke patients[9]. However, this recorded loss of respiratory muscle strength does not necessarily correlate with loss of functional capacity in this population[9], although MIP values have been linked to walking ability[10,11]. It has been demonstrated that MIP and, even more so, MEP values can recover 3 months after stroke, but recovery trends vary among patients[10].

It is noteworthy that respiratory muscle strength measurements vary significantly between males and females, thus norm sets are recorded separately for the two sexes[1]. Males present with 34-66% higher values for MIP and 41-57% higher values for MEP than females[1,12,13]. Also, age has been inversely associated with MIP and MEP and the slope of decline of their values with age progression doesn't vary significantly in literature1. It is possible that this slope is not linear, becoming greater over the age of sixty[1]. However, the lower limit of normal seems to be preserved until the age of seventy, possibly due to the fact that the muscles assessed are also being used for activities other than respiration[1]. Thus, even in deconditioned elderly individuals the minimum strength reserve for respiration is present[1].

Physical activity is another factor that has been associated with respiratory muscle strength in different patient populations. Both inspiratory and expiratory muscle strength have been shown to improve by exercise training in chronic obstructive pulmonary disease patients[14] and a lower physical activity level has been linked to decreased MIP values in individuals with pulmonary hypertension[15]. Significantly lower predicted MIP values have been recorded in stroke patients who don't ambulate within the community than in community ambulators, but this finding didn't also apply to MEP values[11]. In SCI patients, it has been observed that MIP values increase with inspiratory muscle training, either by a flow-resistive or a threshold protocol, with no significant differences between the two[16].

Materials and Methods

Design and setting

In this cross-sectional study, a total of 100 neurorehabilitation patients were evaluated by the same rater from 2018 to 2022, including 50 stroke (23 males, 27 females) and 50 SCI (41 men, 9 women) inpatients and outpatients from the KAT Hospital Rehabilitation Department and the National Rehabilitation Centre in Greece. Sample size was not determined by power analysis but was based on previous literature. The study included adults with ischemic or hemorrhagic stroke and traumatic or non-traumatic spinal cord injury, fluent in the Greek language, able to comprehend the procedure, grant their consent and follow directions. Exclusion criteria included coexisting traumatic brain injury and co-morbidities affecting functional status, known chronic obstructive lung disease or restrictive lung disease, neuromuscular disorders that would affect respiratory muscle strength and presence of contraindications to maximal respiratory strength measurement (recent brain, abdomen, thoracic, eye or inner ear surgery, presence of brain or aortic aneurysm, recent myocardial infraction, pulmonary embolism, pneumothorax, lower respiratory infection, hemoptysis of unknown origin and severe arterial hypertension). Also excluded were patients with major psychiatric or cognitive disorders, who were unable to comply with the measurement procedure.

Demographics and medical history were recorded for all participants, including body mass Index (BMI), major co-morbidities, history of participation in moderate physical activity (150 minutes per week) prior to injury and smoking status. SCI participants were classified based on ASIA guidelines[7,8] into four categories (A, B, C and D).

Respiratory muscle strength was measured by the MicroRPM (Respiratory Pressure Meter) device with a flanged mouthpiece, a portable manometer that has been shown to exhibit satisfactory test-retest reliability for MIP

Table 1. Univariate analysis of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) variables-Spinal Cord Injury group.

		MIP		MEP	
		Median (IQR)	p-value	Median (IQR)	p-value
Sex	male	60.5 (88.0)	0.017	70.5 (78.5)	0.006
	female	42.5 (24.5)		51.0 (34.8)	
Physical activity history	no	42.0 (27.0)	0.030	57.0 (33.5)	0.105
	yes	62.0 (80.5)		65.0 (63.5)	
Smoking	no	54.5 (87.3)	0.801	55.0 (78.8)	0.205
	yes	46.5 (53.3)		68.0 (41.8)	
Diabetes Mellitus	no	55.0 (83.5)	0.013	66.0 (73.0)	0.020
	yes	38.0 (16.0)		51.0 (31.5)	
Hypertension	no	50.5 (72.8)	0.917	65.5 (63.5)	0.240
	yes	47.0 (81.8)		55.0 (57.0)	
ASIA	A	59.0 (97.5)	0.221	56.0 (74.5)	0.142
	B	108.0 (63.5)		102.0 (96.5)	
	C	40.0 (67.5)		47.0 (70.5)	
	D	47.0 (23.0)		66.0 (26.0)	
Age	Spearman's correlation coefficient	r = - 0.453	<0.005	r = - 0.413	<0.005
Weight		r = 0.202	0.160	r = 0.071	0.626
Height		r = 0.399	<0.005	r = 0.430	<0.005
BMI		r = 0.038	0.793	r = -0.068	0.639
MBI total score		r = 0.381	0.006	r = 0.388	0.005
Physical functioning (SF-36)		r = 0.232	0.104	r = 0.286	0.044
Role-physical (SF-36)		r = - 0.327	0.021	r = - 0.180	0.211
Bodily pain (SF-36)		r = 0.126	0.383	r = 0.268	0.060
General health (SF-36)		r = - 0.044	0.762	r = 0.112	0.440
Vitality (SF-36)		r = 0.251	0.078	r = 0.269	0.059
Social functioning (SF-36)		r = 0.285	0.045	r = 0.136	0.347
Role-emotional (SF-36)		r = - 0.041	0.780	r = - 0.283	0.046
Mental health (SF-36)		r = - 0.152	0.292	r = - 0.074	0.608

and MEP measurements[18]. The procedure used was based on American Thoracic Society and European Respiratory Society guidelines[19,20], with the patients examined in a sitting position, executing five maximal inspiratory and five maximal expiratory efforts of 1.5 seconds minimum duration each. There were intervals of rest between efforts, of at least one minute or longer, based on individual needs. Verbal and/or visual feedback was given to participants during measurement, in order to enhance performance, and out of the 5 different values for each variable, the highest achieved was recorded and not the mean value[19,20,21].

All patients were evaluated by interview with the Greek Modified Barthel Index (MBI-Shah version) for establishing ADL performance, as well as with the 36-Item Short Form Survey (SF-36) for health status and quality of life evaluation, with both instruments having already been adapted and validated on a Greek population[17,22-25].

Statistical analysis

Data were expressed as median (IQR) for all the quantitative variables recorded and as percentages for all the qualitative variables. The Kolmogorov-Smirnov test was utilized for normality analysis of the quantitative variables.

Bivariate analysis was applied by using the Mann Whitney test and Spearman's correlation coefficients, in order to analyze the relation between the outcome variables of MIP and MEP and the qualitative, quantitative, demographic and clinical characteristics recorded respectively.

All demographic, clinical variables and assessment questionnaires' total scores which were presented (p-value<0.1) in bivariate analysis, were included in a multiple linear regression model, using the enter method, so as to determine the independent significant factors associated with each of the outcome variables.

All assumptions of linear regression analysis were

Table 2. Univariate analysis of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) variables-Stroke group.

		MIP		MEP	
		Median (IQR)	p-value	Median (IQR)	p-value
Sex	male	30.0 (28.0)	0.915	56.0 (21.0)	0.413
	female	32.0 (21.0)		44.0 (36.0)	
Physical activity history	no	25.0 (14.0)	<0.005	48.0 (30.0)	0.008
	yes	49.0 (26.0)		62.0 (30.0)	
Smoking	no	22.0 (28.3)	0.665	40.0 (42.8)	0.409
	yes	31.5 (10.5)		54.0 (16.0)	
Diabetes Mellitus	no	50.5 (72.8)	0.829	65.5 (63.5)	0.931
	yes	47.0 (81.8)		55.0 (57.0)	
Hypertension	no	32.0 (24.0)	0.365	54.0 (30.0)	0.350
	yes	25.0 (16.0)		44.0 (30.0)	
Age	Spearman's correlation coefficient	r = - 0.353	0.012	r = - 0.399	<0.005
Weight		r = 0.185	0.200	r = 0.241	0.120
Height		r = 0.145	0.316	r = 0.219	0.127
BMI		r = 0.188	0.190	r = 0.202	0.158
MBI total score		r = 0.333	0.018	r = 0.500	<0.005
Physical functioning (SF-36)		r = 0.407	<0.005	r = 0.606	<0.005
Role-physical (SF-36)		r = - 0.222	0.121	r = - 0.257	0.072
Bodily pain (SF-36)		r = -0.095	0.513	r = -0.112	0.437
General health (SF-36)		r = 0.201	0.162	r = 0.245	0.087
Vitality (SF-36)		r = 0.137	0.343	r = 0.146	0.310
Social functioning (SF-36)		r = -0.343	0.015	r = -0.272	0.056
Role-emotional (SF-36)		r = - 0.050	0.731	r = - 0.075	0.603
Mental health (SF-36)		r = 0.268	0.059	r = 0.207	0.149

examined, including homoscedasticity (homogeneity of variances), linearity, normality and independence of error terms, as well as multicollinearity of independent variables.

All tests are two-sided and statistical significance was set at p<0.05. The sum of statistical analysis was carried out using the statistical package SPSS vr 21.00 (IBM Corporation, Somers, NY, USA).

Results

Univariate analysis of Maximal Inspiratory Pressure and Maximal Expiratory Pressure-Spinal Cord Injury group

In SCI participants, age and role-physical subscale of the SF-36 questionnaire were moderately negatively correlated with MIP values (r=-0.453 and r=-0.327 respectively, p<0.05). On the other hand, MBI total score, height and the SF-36 social functioning subscale were moderately positively correlated with MIP (r=0.381, r=0.400 and r=0.285 respectively, p<0.05). Moreover, it was found that males, all SCI patients without diabetes mellitus and those reporting a history of moderate physical activity prior to injury presented with higher values of MIP compared to females, those with diabetes and those without history of physical activity respectively (p<0.05) (Table 1).

Also depicted in Table 1, it was found that both age and the SF-36 role-emotional subscale were low to moderate negatively correlated with MEP (r=-0.413 and r=-0.283 respectively, p<0.05) in the SCI group. On the contrary, MBI total score, height and SF-36 social functioning subscale were low to moderate positively correlated with MEP (r=0.388, r=0.430 and r=0.286 respectively, p<0.05). In addition, male SCI participants and people without diabetes mellitus presented with higher values of MEP, compared to females and those with diabetes mellitus respectively (p<0.05).

Univariate analysis of Maximal Inspiratory Pressure and Maximal Expiratory Pressure-Stroke group

Findings from the univariate analysis of the MIP variable in stroke participants are depicted in Table 2. It was found that age and the SF-36 social functioning subscale were low to moderate negatively correlated with MIP (r=-0.353 and r=-0.343 respectively, p<0.05), whereas MBI total score and the SF-36 physical functioning subscale were low to moderate positively correlated with MIP (r=0.333, r=0.407 respectively, p<0.05). Moreover, results indicated that people with a moderate level of physical activity prior to stroke

Table 3. Multiple linear regression of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) variables-Spinal Cord Injury group.

			Reference category	R^2	Beta coefficient	SE	p-value
MIP	Enter method	Constant	---		135.62	54.86	0.018
		Age	---	18.8%	-1.22	0.48	0.015
		Sex	male	12.2%	-37.34	19.56	0.063
		Physical activity history	no	<0.5%	-0.30	15.39	0.984
		Height	**no**	**Excluded cause of collinearity**			
		Diabetes Mellitus	---	5%	8.95	19.10	0.642
		MBI total score	---	14.3%	0.75	0.24	<0.005
		Bodily pain (SF-36)	---	<0.5%	0.04	0.25	0.860
		Vitality (SF-36)	---	<0.5%	0.09	0.40	0.829
		Role-emotional (SF-36)	---	<0.5%	-0.05	0.23	0.836
	Stepwise method	Constant			137.45	25.28	<0.005
		Age	---	18.8%	-1.09	0.36	<0.005
		Sex	male	12.2%	-38.77	12.10	<0.005
		MBI total score	---	14.3%	0.74	0.20	<0.005
MEP	Enter method	Constant	---		91.884	233.673	0.696
		Age	---	6.6%	-0.95	0.53	0.081
		Sex	male	17.4%	-37.35	20.98	0.083
		Diabetes Mellitus	no	<0.5%	9.45	21.27	0.659
		Height	---	<0.5%	0.35	1.15	0.762
		MBI total score	---	20.2%	0.91	0.26	<0.005
		Bodily pain (SF-36)	---	<0.5%	0.09	0.26	0.743
		Vitality (SF-36)	---	<0.5%	-0.04	0.44	0.930
		Role-emotional (SF-36)	---	2.1%	-0.26	0.21	0.218
	Stepwise method	Constant		142.91	27.66	<0.005	
		MBI total score	---	20.2%	0.87	0.22	<0.005
		Sex	male	17.4%	-43.95	13.24	<0.005
		Age	---	6.6%	-0.93	0.40	0.024

presented with higher MIP values, compared to those not reporting history of that level of physical activity ($p<0.05$).

In the univariate analysis of the MEP variable (Table 2) for the stroke participants, age and the SF-36 social functioning subscale were found to be low to moderate negatively correlated with MEP ($r=-0.400$ and $r=-0.272$ respectively, $p<0.05$). On the contrary, MBI total score and the SF-36 physical functioning subscale were highly positively correlated with MEP ($r=0.500$, $r=0.60$ respectively, $p<0.05$). Moreover, stroke participants who reported moderate physical activity before stroke presented with higher MEP values than those with no such history of physical activity ($p<0.05$).

Multiple linear regression models with enter method were employed in order to examine the contribution of demographic and clinical variables to the dependent variables (MIP, MEP) in both the SCI and stroke groups. Multiple regression models with stepwise method were employed to examine the strongest predictors of all the demographic and clinical variables to the MIP and MEP variable in SCI participants.

Multiple linear regression of Maximal Inspiratory Pressure and Maximal Expiratory Pressure-Spinal Cord Injury group

As depicted in Table 3, height was excluded from the analysis because of collinearity. Regression analysis accounted for 46,0% of the variance in the MIP variable [$R^2=0.460$; F (8.41)=4.36, $p<0.005$]. According to our results, age (Beta coefficient ± SE:-1.22±0.48; $p=0.015$; $R^2=0.066$), sex (Beta coefficient ± SE:-37.35±20.98; $p=0.083$; $R^2=0.174$) and Modified Barthel Index total score (Beta coefficient ± SE: 0.75±0.24; $p<0.005$; $R^2=0.143$) were statistically significant predictors of the MIP variable.

Additionally, regression analysis of stepwise model accounted for 45.3% of the variance in the MIP variable [$R^2=0.453$; F (3.46)=12.71, $p<0.005$]. According to our results, age (Beta coefficient ± SE: -1.09±0.36; $p<0.005$; $R^2=0.066$), sex (Beta coefficient ± SE: -38.77±12.10; $p<0.005$; $R^2=0.174$) and MBI total score (Beta coefficient ± SE: 0.74±0.20; $p<0.005$; $R^2=0.143$) were the strongest statistically significant predictors of the MIP variable.

Table 4. Multiple linear regression of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) variables-Stroke group.

			Reference category	R^2	Beta coefficient	SE	p-value
MIP	Enter method	Constant	---		42.32	23.37	0.077
		Age	---	1.8%	-0.27	0.22	0.235
		Physical activity history	no	27.3%	18.19	5.65	<0.005
		MBI total score	---	8.2%	0.18	0.10	0.089
		Social functioning (SF-36)	---	4.0%	-0.22	0.12	0.080
		Mental health (SF-36)	---	0.8%	0.19	0.24	0.443
MEP		Constant	---		66.83	22.43	0.005
		Age	---	1.3%	-0.27	0.26	0.315
		Physical activity history	no	9.6%	16.75	6.58	0.014
		MBI total score	---	30%	0.42	0.12	<0.005
		Social functioning (SF-36)	---	4.3%	-0.26	0.14	0.071

Table 5. Correlation of Modified Barthel Index (MBI) total score with Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) based on American Spinal Injury Association (ASIA) classification and Neurological Level of Injury (NLI)-Spinal Cord Injury group.

		MIP	MEP
ASIA A (n=9)	MBI total score	0.873	0.923
ASIA B (n=5)		0.948	0.796
ASIA C (n=13)		0.160	0.150
ASIA D (n=23)		0.416	0.421
NLI C4-C5 (n=11)		0.870	0.676
NLI C6-C8 (n=4)		0.961	0.962
NLI T1-T6 (n=6)		0.908	0.920
NLI T7-L4 (n=29)		0.234	0.268

Also, regression analysis accounted for 46.8% of the variance in the MEP variable [R^2=0.468; F(8.41)=4.52, p<0.005] (Table 3). According to our results, age (Beta coefficient ± SE: -0.95±0.53; p=0.081; R^2=0.066), sex (Beta coefficient ± SE: -37.35±20.98; p=0.083; R^2=0.174) and MBI total score (Beta coefficient ± SE: 0.91±0.26; p<0.005; R^2=0.202) were statistically significant predictors of the MEP variable.

In addition, regression analysis of stepwise model accounted for 44.2% of the variance in the MEP variable [R^2=0.442; F(3.46)=12.17, p<0.005]. According to our findings, age (Beta coefficient ± SE: -0.93±0.40; p=0.024; R^2=0.066), sex (Beta coefficient ± SE: -43.95±13.24; p<0.005; R^2=0.174) and the MBI total score (Beta coefficient ± SE: 0.8±0.262; p<0.005; R^2=0.202) were the strongest statistically significant predictors of the MEP variable (Table 3).

Multiple linear regression of Maximal Inspiratory Pressure and Maximal Expiratory Pressure-Stroke group

In the stroke group, regression analysis accounted for 42.1% of the variance in the MIP variable [R^2=0.421; F(5.44)=6.39, p<0.005]. According to the yielded results, moderate level physical activity history prior to stroke (Beta coefficient ± SE:18.2±5.7; p<0.005; R^2=0.273), MBI total score (Beta coefficient ± SE:0.18±0.10; p=0.089; R^2=0.082) and Social functioning subscale of the SF-36 questionnaire (Beta coefficient ± SE:-0.22±0.12; p=0.080; R^2=0.04) were found to be statistically significant predictors of the MIP variable (Table 4).

Also, regression analysis accounted for 45.1% of the variance in the MEP variable [R^2=0.451; F(4.45)=9.26, p<0.005]. According to our results, the statistically significant predictors of the MEP variable were: a history of moderate level physical activity before stroke (Beta coefficient ±

SE:16.8±6.6; p=0.014; R^2=0.096), the MBI total score (Beta coefficient ± SE:0.42±0.12; p<0.005; R^2=0.300) and the SF-36 instrument Social functioning subscale (Beta coefficient ± SE:-0.26±0.14; p=0.071; R^2=0.043) (Table 4).

Correlation between the MBI total score of SCI patients and MIP and MEP values, based on ASIA classification and neurological level of injury, is presented in Table 5. MBI total score correlation with MIP was very high for the ASIA A and B groups (r=0.873 and r=0.948 respectively), and with MEP, very high for the ASIA A (r=0.923) and high for the ASIA B group (r=0.796). It was found moderate for the ASIA D group (r=0.416 for MIP, r=0.421 for MEP) and no correlation was present for the ASIA C group (r=0.160 for MIP, r=0.150 for MEP). Very high correlation was also recorded for the SCI participants in the NLI groups of C4-C5, C6-C8 and T1-T6 (r=0.870, r=0.961 and r=0.908 respectively), with no correlation present in the NLI T7-L4 group (r=0.234). However, it must be noted that these correlations are not particularly valid due to the small number of participants.

Discussion

It has been reported in literature that age is inversely correlated with respiratory muscle strength in the general population and, even though normal values may differ among studies, they present a similar trend of decline[1,12]. This conclusion was also reached by the present study, with univariate analysis findings indicating a moderate negative correlation between age and MIP and MEP values in both stroke and SCI participants. Another factor strongly affecting maximal respiratory pressure is sex[1,12,13]. Different normal values have been set for males and females, with males exhibiting higher measurements for both MIP and MEP[1,12,13]. This result was also reached by our findings, particularly in the SCI group, with male participants presenting with higher values for both MIP and MEP than female participants. This trend was also present in MEP value measurements in the stroke group, but not in MIP.

From the limited available data in literature, one would expect that no correlation would be found between the functional status level of stroke participants, as evaluated by the MBI total score, and their respiratory muscle strength. Martinez Machado et al studied 15 stroke patients by recording their MIP and MEP values, together with their physical function level by the six-minute walk test (6MWT)[9]. They observed that, even though all measured variables (MIP, MEP, 6MWT) were found statistically lower than reference values (p<0.001), no statistically important correlation was found between respiratory muscle strength values and physical function via the 6MWT[9]. Similar results were found by Pompeu et al, who documented MIP and MEP values, the Trunk Impairment Scale, the Functional Independence Measure and the Berg Balance Scale in 15 stroke survivors, but recorded no correlation between respiratory muscle strength and the functional capacity scales used[26]. In this light, the results of the present study depicting statistically important correlation coefficients between the MBI total score and MEP values in both males and females with stroke, as well as between MBI total score and MIP values in females with stroke, are an interesting new finding in a group of 50 participants (27 male, 23 female).

Also, in accordance with previous findings6, we documented a positive trend between the functional status of both male and female SCI participants, as recorded by the Modified Barthel Index total score, and the maximal inspiratory and expiratory pressure values.

In a different population study, Huzmeli et al compared 33 stable angina patients with 30 healthy controls and documented, among other variables, MIP, MEP and the Short Form SF-36 questionnaire[27]. Even though significant lower MIP and MEP patient values were recorded, as well as all other SF-36 subscales were found significantly lower in the patient group compared to the control group, no significant difference was documented in the social functioning subscale scores between the two[27]. However, this was not the case in our study, with findings depicting a moderate positive correlation between the SF-36 social functioning subscale and MIP and MEP values in the SCI population and was even found to be one of the statistically significant predictors of both respiratory muscle strength variables. On the other hand, social functioning was moderately negatively correlated with both MIP and MEP in the stroke group.

It has been observed that physical activity is a factor repeatedly associated with respiratory muscle strength in various patient populations and that both MIP and MEP values improve by exercise training, regardless of the protocol used[11,14-16]. To our knowledge, however, respiratory muscle strength has not been linked before with a personal history of moderate level physical activity, prior to injury. In the present study, SCI patients who practiced moderate physical activity prior to injury had higher MIP measurements. The same was true for stroke participants with such a history, who exhibited higher values in both MIP and MEP, and in the multiple regression model, history of this type of physical activity was found to be a statistically significant predictor of both respiratory muscle strength variables.

There are few studies addressing the impact of diabetes mellitus on respiratory muscle strength indices. Al-Khlaiwi et al assessed respiratory muscle strength in 110 type 2 diabetes mellitus (type 2 DM) patients compared to 119 controls and found that the patient group exhibited significantly lower MIP values than the control group, with no significant difference in MEP values between the two groups[28]. Fuso et al studied 75 type 2 DM patients versus 40 healthy controls and came to similar conclusions regarding diabetes and MIP values negative correlation[29]. On the other hand, Heimer et al examined respiratory muscle strength in 31 type 1 DM patients against an age, sex and weight matched control group and found no significant differences in either MIP or MEP values between the two groups[30]. In our study, we observed that individuals belonging to the SCI population without diabetes mellitus presented with higher values in both MIP and MEP variables, compared to those with diabetes.

Among the limitations of the present study, we must acknowledge that both inpatients and outpatients with stroke and SCI were included, at different phases of their rehabilitation timeline and in post injury time intervals which varied from one month to fifteen years. Sample size determination, though not conducted by power analysis, was based on previous literature. There was also a smaller number of female participants recruited, especially in the SCI group, which, however, is usually the case in SCI demographics. Additionally, the specimen in most SCI subgroups (Table 5) is considered small for reaching statistical conclusions. Finally, it must be noted that personal history of moderate level physical activity was established by participant statement only.

Conclusion

Respiratory muscle strength decline with age progression has been confirmed in both stroke and SCI cohorts. Gender correlation has also been observed, with men exhibiting higher MIP and MEP values in the SCI group and higher MEP, but not MIP, in the stroke group. In the ASIA D SCI subgroup, the MBI total score in males and females was moderately positively correlated with MIP and MEP values. In the stroke group, positive correlation was found between MBI total score and MEP for both sexes and MBI total score and MIP in females. The SF-36 social functioning subscale presented moderate positive correlation with MIP and MEP in SCI, but moderate negative correlation with both variables in stroke patients. SCI participants without diabetes mellitus exhibited higher maximal respiratory strength values compared to those with diabetes. An interesting finding was that a personal history of moderate level physical activity prior to injury was linked to higher MIP and MEP values in the stroke group and to higher MIP measurements in SCI individuals. Bearing in mind the limitations of the present study, we conclude that age, sex, functional capacity, SCI classification, quality of life components, history of physical activity and diabetes influence respiratory muscle strength in the studied population. We believe our findings could influence rehabilitation planning and decision making in clinical practice for SCI and stroke patients based on their different demographics and co-morbidities.

Ethics approval

The study was approved by the research ethics committees of the two hospitals, KAT Hospital in Athens (protocol number 25/05-12-2017, approval date: December 6th, 2017) and the National Rehabilitation Centre in Ilion (protocol number 05/13-02-2018, approval date: February 2nd, 2018), before recording began.

This research study was conducted in compliance with the World Medical Association Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects.

Consent to participate

All patients provided their informed consent to participate in the present study.

References

1. Evans JA, Whitelaw WA. The Assessment of Maximal Respiratory Mouth Pressures In Adults. Respir Care 2009;54(10):1348–1359.
2. DePalo V, McCool F. Respiratory muscle evaluation of the patient with neuromuscular disease. Semin Respir Crit Care Med 2002;23(3):201-209.
3. Vitacca M, Paneroni M, Bianchi L, Clini E, Vianello A, Ceriana P et al. Maximal inspiratory and expiratory pressure measurement in tracheotomised patients. European Respiratory Journal 2006;27:343-349.
4. Arora NS, Rochester DF. Respiratory muscle strength and maximal voluntary ventilation in undernourished patients. Am Rev Respir Dis 1982;126(1):5-8.
5. Schoser B, Fong E, Geberhiwot T, Hughes D, Kissel JT, Madathil SC et al. Maximum inspiratory pressure as a clinically meaningful trial endpoint for neuromuscular diseases: a comprehensive review of the literature. Orphanet J Rare Dis 2017;16:12(1):52.
6. Mateus SRM, Beraldo PSS, Horan TA. Maximal static mouth respiratory pressure in spinal cord injured patients: correlation with motor level. Spinal Cord 2007; 45:569- 575.
7. American Spinal Injury Association. International Standards for Neurological Classification of Spinal Cord Injury. Available at: https://asia-spinalinjury.org/wp-content/uploads/2016/02/International_Stds_Diagram_Worksheet.pdf. (accessed 20 September 2023).
8. Maynard Jr FM, Bracken MB, Creasey G, Ditunno JF Jr, Donovan WH, Ducker TB et al. International Standards for Neurological and Functional Classification of Spinal Cord Injury. American Spinal Injury Association. Spinal Cord 1997;35:266–274.
9. Martinez Machado ACM, Marinho Silva NG, Do Carmo Leite Diniz G, Porto Pessoa B. Respiratory function and functional capacity in chronic stroke patients. Fisioter Mov 2016;29(1): 95-102.
10. Kubo H, Nozoe M, Yamamoto M, Kamo A, Noguchi M, Kanai M et al. Recovery process of respiratory muscle strength in patients following stroke: A Pilot Study. Phys Ther Res 2020;23(2):123-131.
11. Pinheiro MB, Polese JC, Faria CD, Machado GC, Parreira VF, Britto RR et al. Inspiratory muscular weakness is most evident in chronic stroke survivors with lower walking speeds. Eur J Phys Rehabil Med 2014;50:301-307.
12. Hautmann H, Hefele S, Schotten K, Huber RM. Maximal inspiratory mouth pressures in healthy subjects: what is the lower limit of normal? Respir Med 2000;94(7):689-693.
13. Harik-Khan R, Wise RA, Fozard JL. Determinants of maximal inspiratory pressure. Am J Respir Crit Care Med 1998;158(5):1459-1464.
14. Chiu KL, Hsieh PC, Wu CW, Tzeng IS, Wu YK, Lan CC. Exercise training increases respiratory muscle strength

and exercise capacity in patients with chronic obstructive pulmonary disease and respiratory muscle weakness. Heart & Lung 2020;49(5):556-563.
15. Aslan GK, Akinci B, Yeldan I, Okumus G. Respiratory muscle strength in patients with pulmonary hypertension: The relationship with exercise capacity, physical activity level, and quality of life. Clin Respir J 2018;12(2):699-705.
16. Palermo AE, Butler JE, Boswell-Ruys CL. Comparison of two inspiratory muscle training protocols in people with spinal cord injury: a secondary analysis. Spinal Cord Ser Cases 2023;9(1):42.
17. Ferfeli S, Galanos A, Dontas IA, Triantafyllou A, Triantafyllopoulos IK, Chronopoulos E. Reliability and validity of the Greek adaptation of the Modified Barthel Index in neurorehabilitation patients. Eur J Phys Rehabil Med 2024;60(1):44-54.
18. Dimitriadis Z, Kapreli E, Konstantinidou I, Oldham J, Strimpakos N. Test/Retest Reliability of Maximum Mouth Pressure Measurements With the MicroRPM in Healthy Volunteers. Respiratory Care Jun 2011;56(6):776-782.
19. American Thoracic Society/European Respiratory Society. ATS/ERS statement on respiratory muscle testing. Am J Respir Crit Care Med 2002;166(4):518-624.
20. Laveneziana P, Albuquerque A, Aliverti A, Babb T, Barreiro E, Dres M et al. ERS statement on respiratory muscle testing at rest and during exercise. Eur Respir J 2019; 53:1801214
21. Hamnegård CH, Wragg S, Kyroussis D, Aquilina R, Moxham J, Green M. Portable measurement of maximum mouth pressures. Eur Respir J 1994;7:398-401.
22. Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. Maryland State Med J 1965;14:61– 65.
23. Shah S, Vanclay F, Cooper B. Improving the sensitivity of the Barthel Index for stroke rehabilitation. Journal of Clinical Epidemiology 1989;42:703-709.
24. Pappa E, Kontodimopoulos N, Niakas D. Psychometric evaluation and normative data for the Greek SF-36 health survey using a large urban population sample. Archives of Hellenic Medicine 2006;23(2):159–166.
25. Pappa E, Kontodimopoulos N, Niakas D. Validating and norming of the Greek SF-36 Health Survey. Quality of Life Research 2005;14:1433-1438.
26. Pompeu SMAA, Pompeu JE, Rosa M, Silva MR. Correlação entre função motora, equilíbrio e força respiratória pós Acidente Vascular Cerebral. Rev Neurocienc 2011;19(4):614-20.
27. Huzmeli I, Ozer AY, Akkus O, Katayıfcı N, Sen F, Yurdalan SU et al. Comparison of functional exercise capacity, quality of life and respiratory and peripheral muscle strength between patients with stable angina and healthy controls. J Int Med Res 2020; 48(12):300060520979211.
28. Al-Khlaiwi T, Alsabih AO, Khan A, Habib SH, Sultan M, Habib SS. Reduced pulmonary functions and respiratory muscle strength in Type 2 diabetes mellitus and its association with glycemic control. Eur Rev Med Pharmacol Sci 2021;25(23):7363-7368.
29. Fuso L, Pitocco D, Longobardi A, Zaccardi F, Contu C, Pozzuto C et al. Reduced respiratory muscle strength and endurance in type 2 diabetes mellitus. Diabetes Metab Res Rev 2012;28(4):370-375.
30. Heimer D, Brami J, Lieberman D, Bark H. Respiratory Muscle Performance in Patients with Type 1 Diabetes. Diabetic Medicine 1990;7:434-437.