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CHARACTERISTICS OF THE INSPIRATORY MUSCLE STRENGTH IN THE WELL-TRAINED MALE AND FEMALE ATHLETES

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Abstract: Measurement of the maximal inspiratory mouth pressure (PImax) is a simple, reproducible, and non-invasive method frequently used for estimation of the inspiratory muscle strength. The aim of the study was to assess the PImax values in well-trained representatives of the endurance sports and to determine the basic relationships between these values and age, training experience, somatic indices and aerobic capacity of the tested subjects. Overall, thirty female and thirty-five male elite junior and senior representatives of the endurance sports were included in the investigation. PImax and maximal oxygen uptake (VO_2max) were estimated in all the subjects. In the female athletes the obtained mean PImax values (118±24 cm H_2O) were significantly lower than the respective values estimated in their male counterparts (143±25 cm H_2O). Of all the tested relationships significant correlation was detected only between PImax and VO_2max in the females (r=0.475) and only between PImax and the body mass index (BMI) in the males (r=0.501). Since the published values of PImax vary greatly depending, among other factors, on the studied population, methods and techniques of the measurement and motivation of the tested subjects it is suggested that each laboratory elaborate its own reference values. The results indicate that in the female and in the male athletes the inspiratory muscle strength is not related to the body size. On the other hand, the detected correlation between PImax and BMI in the males may suggest a possible relationship between the inspiratory muscle strength and the total muscle mass. Presumably, endurance training in the well-trained individuals can not enhance any more the inspiratory muscle strength or the described relationships are indirect and depend on the intersexual differences.

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Key words: Well-trained male and female athletes - Endurance training - Inspiratory muscle strength

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Introduction

Results of the recent investigations indicate that even in the elite athletes conventional training does not ensure the attainment of the optimal training status of the respiratory muscles. In fact, it has been demonstrated that these muscles, just like other skeletal muscles, fatigue during exercising [3,10,12,13,17,20]. Hence, one of the frequently utilized method for the assessment of the functional status of the respiratory muscles in athletes is measurement of the maximal inspiratory mouth pressure (PImax). Indeed, this is a simple, reproducible, and non-invasive way to estimate the inspiratory muscle strength [14,21]. PImax reflects the capacity to generate strength by the combined maximal activity of the inspiratory muscles in the course of a brief, nearly static, contraction during the almost complete closure of the air flow through the respiratory tract. In order to assess the effect of the endurance training on the function of the respiratory muscles PImax was measured in representative groups of the elite male and female athletes with the long training experience.

The present study was aimed at estimation of the PImax values in the well-trained representatives of the endurance sports as well as at determination of the basic relationships between these values and age, training experience, somatic indices and aerobic capacity of the tested subjects.

Materials and Methods

Table 1
Basic characteristics of the tested female (n=30) and male (n=35) athletes

Group of athletes	Age (years)	Body height (cm)	Body mass (kg)	BMI (kg/m^2)	Training experience (years)	VO_2max (ml/kg/min)
Females	19.8	175	67.4	21.9	6.0	51.5
	±3.3	±10	±9.8	±1.8	±3.4	±6.1
Males	24.8	190	85.2	23.9	10.3	62.4
	±3.9	±10	±10.9	±1.6	±4.0	±4.7

Estimation of the maximal inspiratory pressure (PImax): PImax was measured in all the subjects according to the procedure described previously by other authors [9,16,21]. Briefly, the subjects performed minimally ten and maximally fifteen technically satisfactory inspirations and the highest of three measurements with

less than 5% variability was regarded as maximum. The initial length of the respiratory muscles was controlled by initiating each effort from the residual volume (RV). All the tests were performed in a sitting position, the subjects were verbally encouraged to help the subjects perform maximally and the visual feedback values were informing them about the measured inspiratory pressure. The measurements were carried out using the electronic equipment supplied with the Lungtest 1000 computer software (MES, Krakow, Poland) capable of transmitting the pressure from the site of the measurement (the mouthpiece) to the pressure sensors.

Estimation of the maximal oxygen uptake (VO_2max): The subjects performed routine incremental exercise tests either on a mechanical treadmill (biathletes and cross-country skiers) or on the Concept II rowing ergometer (rowers); the tests lasted 5 or 3 min, respectively. The exercises on the mechanical treadmill and the rowing ergometer were interrupted by the 1-minute or 30-second breaks, respectively. The oxygen uptake was estimated with the breath by breath (BxB) assay using the series Vmax 29 apparatus (SensorMedics, Yorba Linda, CA, USA). Prior to each test the CO_2 and O_2 calibrations were performed using the certified calibration gases. Calibration of the volume was made with use of a 3-liter syringe.

Statistical calculations: Mean values and standard deviations (SD) were calculated and significance of the differences was assessed using the Student's t test for independent trials. The normality of the distribution of the tested variables was checked using the Shapiro-Wilk test and correlation between the variables was estimated based on the value of the Pearson's correlation coefficient.

Results

In the female athletes the obtained mean PImax values (118±24 cm H_2O) were significantly lower than the same values obtained in their male counterparts (143±25 cm H_2O) (Fig. 1). Based on the mean values and standard deviations confidence intervals were calculated for the PImax values which were stratified into low, medium and high levels (Table 2); arithmetical mean ±0.5 SD was regarded as medium assuming that at normal distribution of the tested feature each of the three levels will cover approximately 33% of all the results.

With respect to relation between the PImax and the age, training experience, somatic indices or maximal oxygen uptake of the tested subjects significant correlation was detected only between PImax and VO_2max in the females (r=0.475) and only between PImax and the body mass index (BMI) in the males (r=0.501) (Table 3, Fig. 2 and 3).

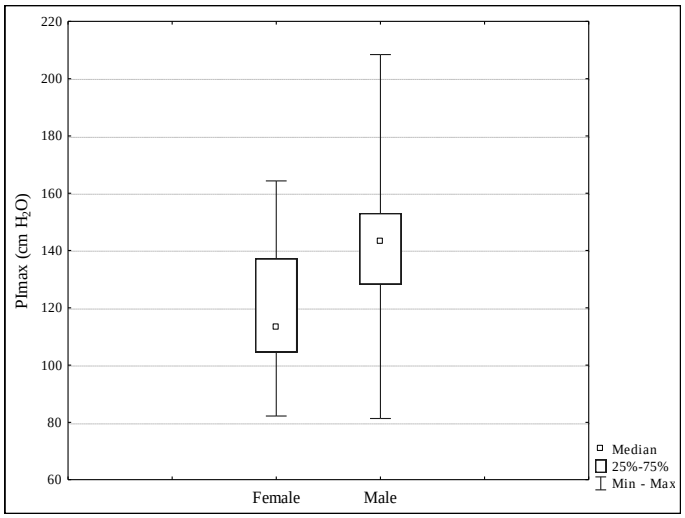

Fig. 1
Maximal inspiratory mouth pressure (PImax) values measured in the tested groups of female (n=30) and male (n=35) athletes

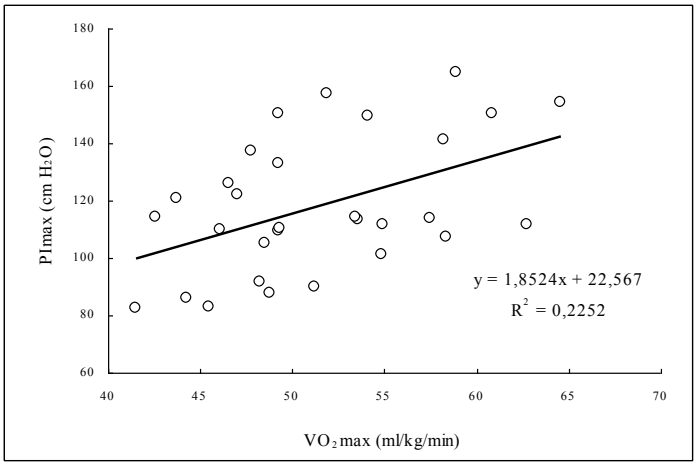

Fig. 2
Significant correlations (r=0.475, p<0.01) between maximal inspiratory mouth pressure (PImax) and maximal oxygen uptake (VO_2max) in the tested female athletes (n=30)

Table 2
Mean values and confidence intervals of the maximal inspiratory mouth pressure (PImax) based on measurements performed in the female (n=30) and male (n=35) representatives of the endurance sports

	PImax (cm H_2O)	
PImax level	Females	Males
Mean ± SD	118±24	143±25*
Low	≤105	≤130
Medium	106-130	131-156
High	≥131	≥157

* - statistically significant difference ($p<0.001$)

Table 3
Coefficients of the simple correlation between the maximal inspiratory mouth pressure (PImax) and the age, somatic indices, training experience and maximal oxygen uptake determined in the female (n=30) and male (n=35) athletes

Parameter	PImax (cm H_2O)	
	Females	Males
Age (years)	0.264	-0.299
Body height (cm)	-0.170	0.007
Body mass (kg)	-0.200	0.264
BMI (kg/m^2)	-0.173	0.501**
Training experience (years)	0.300	-0.176
VO_2max (l/min)	0.224	0.334
VO_2max (ml/kg/min)	0.475**	0.187

** - statistical significance of the correlation coefficient ($p<0.01$)

Discussion

The results of the present study indicate that, as reported by other authors who tested non-training individuals [2,4,8], the inspiratory muscle strength was significantly greater in the well-trained male athletes than in their female

counterparts. Notably, the measured PImax values varied substantially within the tested groups of the subjects: in the female athletes the maximal values (164 cm H_2O) were twice as high as the minimal values (82 cm H_2O), while in the male athletes the maximal and minimal values equaled to 208 and 81 cm H_2O, respectively (Fig. 1). According to McConnell *et al.* [13], respiratory muscles of the athletes presenting with low PImax are more susceptible to the exercise-induced fatigue. As indicated by numerous studies [11,15,18,19] for the enhancement of the strength of these muscles a separate, specifically designed training protocol based on devices which increase the inspiratory resistance is necessary.

The published reference values of PImax vary to a great extent depending, among other factors, on the population under study, methods and techniques of the measurement as well as motivation of the tested subjects. In two previous investigations performed on the small groups of adolescent and adult subjects [5,7] no significantly higher PImax values were demonstrated in trained athletes compared to non-training individuals and only a tendency toward greater inspiratory muscle strength could be detected in the former subjects [7]. Likewise, Ker and Schultz [10] were unable to demonstrate any markedly higher PImax values in the marathon runners compared to non-training subjects. This lack of the significant differences may be explained by the results of Fuso *et al.* [9] who showed that estimations of the inspiratory muscle strength measured beginning from the functional residual capacity (PImaxFRC) are more diagnostically reliable for differentiation between training and non-training subjects than are the usually performed estimations based on measurements starting from the residual volume (PImaxRV).

The values of PImax obtained in the present study are generally higher than those reported by other investigators who tested athletes from various sports (Table 4). Since, as noted earlier, it is difficult to compare results coming from different authors own reference values have been elaborated for both male and female representatives of the endurance sports (Table 2).

Obviously, the essential issue concerns the factors which affect the inspiratory muscle strength in the well-trained athletes. In the present investigation the correlations between PImax and the analyzed indices were quite unclear. In fact, among the tested relationships between PImax and the age, training experience, somatic indices and level of aerobic capacity significant correlation was detected only for VO_2max in the female athletes (Fig. 2, Table 3) and only for the body mass index (BMI) in the male athletes (Fig. 3). With respect to the latter group of the subjects, other authors who tested moderately trained men were also unable to

detect any appreciable correlations between PImax and VO_2max, body height and body mass [13]. These results indicate that in the tested male and female athletes the inspiratory muscle strength is unrelated to the body size. On the other hand, the detected correlation between PImax and BMI in the male subjects may point to a relationship between the inspiratory muscle strength and the total muscle mass. Indeed, the tested male representatives of the endurance sports generally presented with the relatively low body fat content (8-14%) and their higher BMI values resulted from the increased fat-free mass.

Table 4
Mean values of the maximal inspiratory mouth pressure (PImax) registered in non-training individuals and in athletes from various sports (comparison of the published data)

Author	Group of subjects	Age (years)	Females N	Females PImax (cm H_2O)	Males N	Males PImax (cm H_2O)
Black and Hyatt [2]	Non-training individuals	20-54	60	87±16	60	124±22
Chen and Ching-Su [4]		16-30	20	89±14	20	123±25
Fiz et al. [8]		20-29	10	90±26	10	135±33
McConnell et al. [13]	Moderately-trained individuals	23±2.8			24	158±29
Fuso et al. [9]	Elite soccer players	23±3			27	114±32
Romer et al. [15]	Cyclists and triathletes	29.5±3.3 E 30.3±2.6 C			16	102±6 E 100±6 C
Volianitis et al. [19]	Elite female rowers	23.8±3.8	14	104±8 E 130±12 C		
Klusiewicz et al. [11]	Elite rowers	24.8±3.2			15	157±23
Present studies	Representatives of endurance sports	17-34	30	118±24	35	143±25

E – experimental group, C – control group

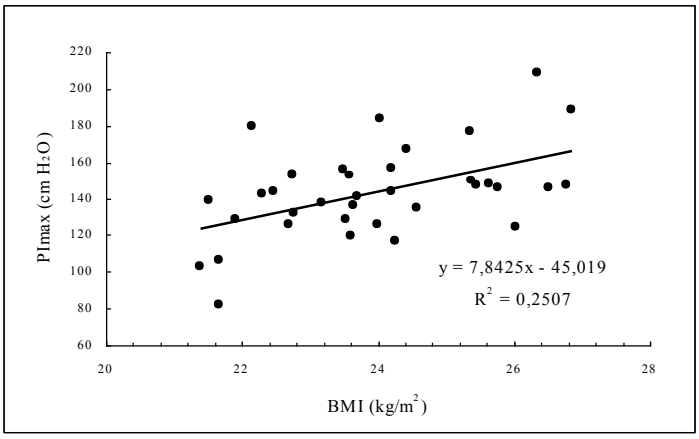

Fig. 3
Significant correlations (r=0.501, p<0.01) between maximal inspiratory mouth pressure (PImax) and body mass index (BMI) in the tested male athletes (n=35)

In view of the fact that both the female and male athletes investigated in the present study demonstrated homogenous values of VO_2max (51.5±6.1 and 62.4±4.7 ml/kg/min, respectively) the detected significant correlation between PImax and VO_2max in the former but not in the latter subjects is difficult to explain. Presumably, further endurance training in the already well-trained individuals, such as the tested male athletes, does not enhance any more the inspiratory muscle strength or, alternatively, the described relationships are indirect and depend on the intersexual differences. In fact, as shown previously by us, no significant alterations in the inspiratory muscle strength could be detected in the elite rowers subjected to the 6-month training cycle [11]. Likewise, other authors could not demonstrate any significant differences in PImax between three groups of athletes of various training practices [1]. Noticeably however, the reported data on the effect of the endurance training on changes in PImax have not been consistent. For example, Clanton *et al.* [6] demonstrated a marked improvement of the strength and endurance of the inspiratory muscles as a result of the 12-week swim training.

The relationship between the inspiratory muscle strength and age is still a subject of minor controversy. In the present investigations carried out on athletes from the relatively narrow age-groups (17-31 years in case of the females and 19-34 years in case of the males) did not demonstrate any significant correlations with PImax. Similarly, no significant decrease of PImax with age was detected in non-training subjects younger than 55 years [2], while a negative correlation was

demonstrated in subjects aged 13 to 77 years [9] and 20 to 70 years [8]. Also, Chen and Ching-Su [4] showed that the inspiratory muscle strength in the 16- to 75-year-old subjects substantially decreases with age.

Conclusions

The published values of PImax vary greatly depending, among other factors, on the population under study, methods and techniques of the measurement and motivation of the tested subjects. It is recommended therefore that each laboratory elaborate its own reference values of this index. Similar to the reports of other authors who tested non-training subjects, the present findings clearly demonstrate that inspiratory muscle strength in the well-trained male athletes is significantly greater than in their female counterparts. The results also indicate that in the female and in the male athletes the inspiratory muscle strength is not related to the body size. Presumably, endurance training in the already well-trained individuals does not enhance any further the inspiratory muscle strength or, alternatively, the described relationships are less direct and depend on the intersexual differences.

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