SOME PARAMETERS OF ISOMETRIC STRENGTH AS A MEASURE OF MUSCULAR ENDURANCE

by

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In the aim to determine muscular endurance, isometric contractions were used. Four different experimental sets were applied. They were measured endurance time (in s) in three tests: $\mathbf{t_{75\%Fmax}}$, $\mathbf{t_{50\%Fmax}}$, and $\mathbf{t_{25\%\ Fmax}}$. All of them were performed until exhaustion. Decrease of muscular strength in 20s maximal voluntary contraction (MVC) was recorded in the last experiment. Reduce of force and speed of this process was described using relative and absolute parameters. In every case, the period between experiments was one week.

The muscles of dominant hand were investigated in 168 males and 256 females. The results of researches were processed statistically and discussed. It seems, that maximal voluntary contraction (MVC) could be used to describe muscle fibers composition. Generally, isometric contraction describes muscular endurance rather poor. It is possible to estimate muscular endurance within the same subject (or subjects at the same level of muscular force) using the set force of 50% Fmax until exhaustion ($\mathbf{t_{50\%Fmax}}$).

Key words: muscular force, isometric contraction, muscular endurance

Introduction

The endurance in relation to human and his biomechanical parameters, used in the theory of physical education and sport, is very controversial. In mechanics the notion of endurance is strictly defined and means the resistance of material to devastating external forces, while in physical education appears as ability to long-term continuation of work with determined intensity and with lack of fatigue (Fidelus 1983, Sozanski 1999). This human body feature is

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very complex and depends upon many factors with the background of metabolic processes, muscle structure etc.

The specific form of this ability evaluation is different tests, with the basis focused on long-term isometric contraction. It includes: hanging on bar with flexed arms, sit-up with body extended in 45° backwards etc. These tests are very popular, and its results were used very often to research related to determination of endurance development as a motor ability (Kasperczyk 1990). The most often used method is observation of specific muscle groups during long-time isometric contractions

In order to unify the test protocols the similar force values is always set i.e. 50% of maximal force of the specific functional group. The measure of endurance is in that case time to exhaustion (endurance time) (Cotzias and Marshall 1993, Seals 1993). Some of the results are so unreliable (Wolanski and Parizková 1976, Kasperczyk 1990), which it is worthy to attempt to build the objective method of such measurements. Handgrip strength endurance evaluations, s well as other muscle groups, clearly suggest the existence of strong sexual dimorphism (West et al. 1995) – females showed significantly higher level of muscle endurance.

Independently from the mentioned above endurance testing protocols, the observation focused quite often on maximal force isometric contraction, where the changes of the force of chosen muscle group are diagnosed in different time intervals or in attempt until exhaustion (Dworak and Haremza 1985, Wit et al. 1999).

The main aim of this research was the answer to following questions appeared after analysis of existing literature data in area of human hand endurance:

1. Is it possible that endurance time of handgrip at maximal force or its lower level, may be the reliable marker of “muscle endurance”?
2. What is the optimal value of resistance in evaluation of “muscle endurance”?
3. Is the advantage of females in muscle endurance caused by sexual dimorphism?

The research was conducted on 168 males and 256 females between the ages 20–23. Among subjects 12% of males and 8% of females were left-handed. The average values of body mass and height in males and females were respectively: 76,10±9,11 kg and 1,81±0,06m and 58,05±6,24 kg and 1,67±0,06 m.

The equipment and technique for measuring force and endurance parameters were essentially the same as has been described previously (Staszkiewicz et al. 2002). The force transducer (Hottinger U9B/2kN) and specially constructed hand dynamometer were used. In every subject, the distance between resistance points of dynamometer holder was in position, which allows pressing with middle phalanx (fig. 1). Subjects were placed in an experimental chair with three-dimension regulation system. Its construction allowed considering different body dimensions.

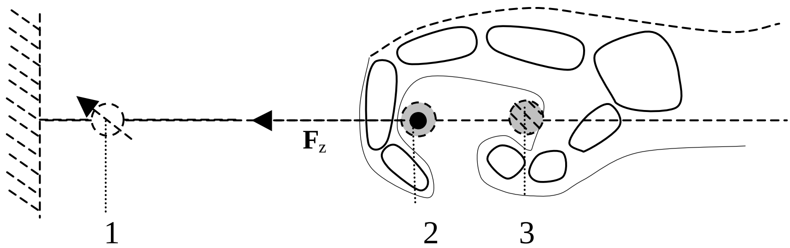

Fig. 1. Conceptual scheme of a measuring stand: (top view): 1 – force transducer, 2 –distant and 3 – proximal dynamometer holder

After standardization of measuring stand, maximal handgrip strength of dominant hand (**F_{max}**) in isometric condition was determined. Following measurements were performed in order to determine endurance time until exhaustion, at the three different intensities: 25%, 50% and 75% of maximal voluntary contraction (MVC) – respectively: **$t_{25\%Fmax}$, $t_{50\%Fmax}$, $t_{75\%Fmax}$**.

At the same conditions, changes of handgrip force in continuous (20s) maximal isometric contraction were recorded. The period between all four tests was one week. The visual feedback of produced force was presented on computer screen, with the aim of helping tested subject in endurance time measuring.

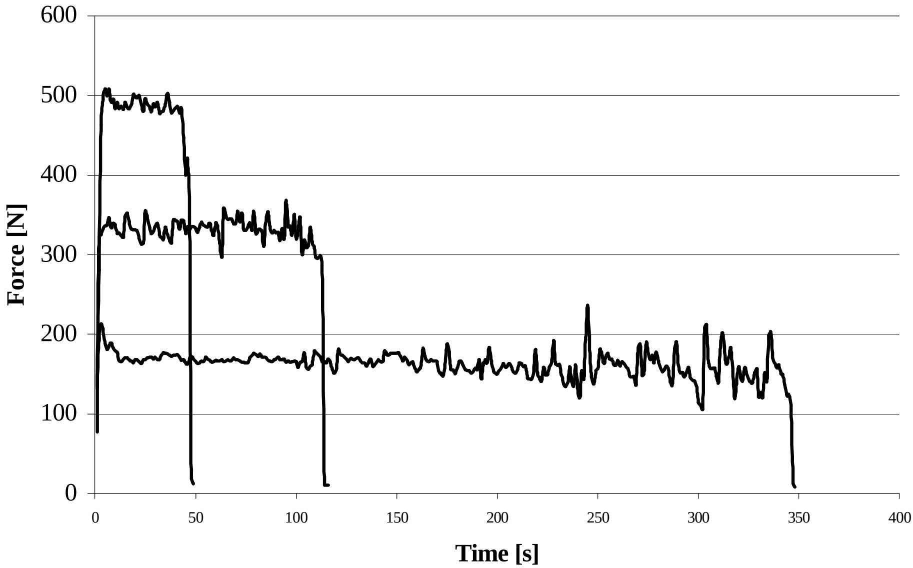

Fig. 2. Changes of endurance time: 75, 50 and 25% Fmax in one of measured subject (maximal handgrip strength was equal 660 N)

During registration, the continuous maximal voluntary contraction (MVC), immediately after maximal value of this variable (**F_{max}**) linear decreases of handgrip strength were observed (fig. 3). With the use of smallest squares estimation method the function describing the relationship F=f(t) was formulated.

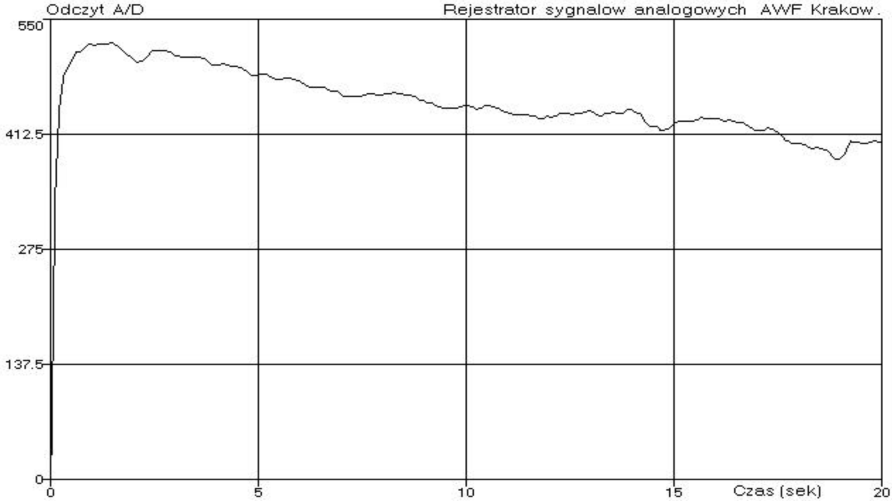

Fig. 3. Decrease of handgrip strength during continuous maximal isometric conditions

The absolute reduction of handgrip strength during 20 s was expressed by difference output value (**F_{max}**) and terminal (**F_{min}**); relative decrease was described in percent of maximal value noted at initial part of experiment. Therefore the rates of handgrip force reduction are described by two indexes: D**F** [N] and D**$F_{\%}$**, [%]. The speed of handgrip force reduction in time is also described by two indexes: absolute D**F/**D**t** [N/s] and relative D**$F_{\%}$**/D**t** [%/s].

Results of investigation were elaborated by basic statistical analysis (descriptive statistics and Pearson linear correlation) in two ways: first for both sexes, second for groups of subjects on different level of muscle force. Maximal handgrip strength (**F_{max}**) was discriminant of division.

The groups I (MI and FI) content the strongest men and women: **F_{max}** was more than the value ($\overline{X}$+0,5 SD). In the groups MII and FII, there were subjects on the middle level of handgrip force: **F_{max}** was comprised in range ($\overline{X}$±0,5 SD). Maximal handgrip force from weakest groups (MIII and FIII) was less than value ($\overline{X}$–0,5 SD).

Endurance time

The registered during research maximal handgrip force (F_{max}) was by 70% higher in males than in females, what resulted in respectively lower resistance applied in endurance tests. The data presented in table 1 show that average time of contraction with the force equal to 75%Fmax ($t_{75\%Fmax}$) was shorter than 1 min., but longer on average by 8 s (22%) in females.

The attempts with lower resistance (**$t_{50\%Fmax}$, $t_{25\%Fmax}$**) were characterized with increased time of trial. The difference in test 50Fmax between females and males was on average 20 s (24,6%), while trials with the smallest resistance (25%Fmax(did not differ groups significantly. When establishing the endurance time from the test with greatest resistance as 1 then the endurance time in attempts from the smallest is equal to 10 : 2 : 1 in females and 8 : 2 : 1 in males.

The observation of average endurance times in groups separated on the basis of Fmax (table 1) showed that the longest time of highest resistance contraction ($t_{75\%Fmax}$) was registered in weakest females (FIII group), the smallest values of described variable in the strongest males (MII group). The decrease in level of maximal force was related to increase of endurance time of isometric contraction. In each endurance test (**$t_{75\%Fmax}$, $t_{50\%Fmax}$, $t_{25\%Fmax}$**) better results were acquired by subjects presenting lower level of maximal force (the only one exclusion were the results of MII group during attempt with the smallest resistance).

Table 1. Descriptive statistics of endurance time at the measured groups

	$t_{75\%Fmax}$ [s]			$t_{50\%Fmax}$ [s]			$t_{25\%Fmax}$ [s]		
	$\overline{x} \pm SD$	**min**	**max**	$\overline{x} \pm SD$	**min**	**max**	$\overline{x} \pm SD$	**min**	**max**
M	36,7±10,1	20,0	71,3	79,2±24,4	34,5	183,9	362,1±125,3	139,0	787,0
F	44,8±18,9	9,3	102,0	98,7±37,2	28,1	273,6	363,6±134,2	90,0	789,0
M I	32,7±7,4	21,5	43,7	66,5±17,9	34,5	102,5	332,0±97,4	196,0	591,0
M II	36,2±8,4	25,7	53,7	75,0±15,0	45,3	111,2	321,4±100,7	147,0	494,7
M III	39,6±11,8	20,0	71,3	94,3±28,6	52,7	183,9	411,2±142,3	139,0	787,0
F I	38,6±15,7	11,7	84,7	88,06±27,8	29,3	173,9	301,7±80,4	90,0	478,9
F II	43,0±14,8	9,3	88,5	97,3±37,1	28,1	273,6	395,1±133,6	191,0	736,0
F III	64,0±22,7	18,6	102,0	111,5±42,2	39,6	241,9	439,4±178,2	185,5	789,0

M – male, F – female, MI and FI - the strongest subjects, MII and FII – subjects presented the middle level of handgrip strength, MIII and FIII – the weakest subjects of both sexes.

Changes of handgrip strength during 20s of maximal voluntary isometric contraction (MVC)

The values presented in table 2 describe the maximal voluntary isometric contraction during 20 s. Absolute force decrement (**?F**) equaled in males approx. 200 N and is twice as high as in females. The relative force decrement (**?F%**) is similar in both sexes and equaled approx. 30%.

Absolute rate of force value decrement (   ) is in females almost twice time smaller than in males (respectively 6,3 and 11 N/s), while relative rate of force decrement ($\frac{?F_{\%}}{?t}$), is almost identical in both sexes and equals 1,6% F_{max}/s.

The results recorded in the weakest, medium, and the strongest showed that (**?F**) are greatest in the strongest subjects, and the smallest in the weakest ones. Relative values (**?$F_{\%}$**) is quite similar in no divided groups at the level of average values (approx. 30% of F_{max}).

The highest absolute rate of force decrement ($\frac{?F}{?t}$) was observed in MI males group (more than 14N/s), and smallest in FIII females group (5,3 N/s). In both sexes the index comes to smaller values simultaneously with the decrease of maximal handgrip force (**F_{max}**), while relative rate of force decrement ($\frac{?F_{\%}}{?t}$) changes only slightly without sexual dimorphism or group separation (equal always slightly above 1,6% F_{max}/s).

Table 2. Characteristic of handgrip strength decrease in 20s maximal voluntary contraction (MVC) – see "Material Methods" for details.

		? F [N]			? $F_{\%}$ [%]			[N/s]			[%/s]		
	n	$\overline{x}$ **±SD**	**min**	**max**	$\overline{x}$ **±SD**	**min**	**max**	$\overline{x}$ **±SD**	**min**	**max**	$\overline{x}$ **±SD**	**min**	**m**
M	**168**	193,8±75,6	78,4	551,3	29,5±9,7	12,5	60,9	11,0±4,6	4,2	29,5	1,67±0,6	0,73	3
F	**256**	112,9±39,0	21,8	266,3	29,4±8,9	6,6	61,2	6,3±2,1	1,2	15,3	1,64±0,5	0,37	3
M I	**52**	245,7±91,3	93,2	551,3	32,1±11,4	12,5	60,5	14,2±5,6	5,5	29,5	1,85±0,7	0,73	3
M II	**57**	179,7±55,4	106,0	333,3	27,5±8,1	15,5	50,1	10,0±3,3	5,7	23,0	1,53±0,5	0,84	3
M III	**59**	161,7±50,1	78,4	332,8	29,3±9,2	14,3	60,9	9,1±2,7	4,2	17,9	1,64±0,5	0,79	3
F I	**79**	136,0±42,8	65,6	266,3	29,9±9,4	15,5	61,2	7,5±2,3	3,6	15,3	1,65±0,5	0,83	3
F II	**100**	110,5±34,3	38,4	224,3	28,9±8,9	9,2	53,2	6,1±1,9	2,1	12,1	1,61±0,5	0,51	2
F III	**77**	92,3±26,5	21,8	167,7	29,5±8,5	6,6	53,6	5,3±1,6	1,2	10,0	1,68±0,5	0,37	3

Correlation between values of handgrip strength, endurance time and parameters measured in MVC

The relationships between handgrip force (Fmax) and endurance times (**$t_{25\%Fmax}$**, **$t_{50\%Fmax}$**, **$t_{75\%Fmax}$**) are negative and the level of correlations is equal from – 0,25 to – 0,50. The correlation coefficients between particular endurance times shows strong, positive relationships between tests with different loads and equals in women and men respectively from 0,60 to 0,67 and from 0,28 to 0,55. The strongest correlation appeared in males between **$t_{75\%Fmax}$** and **$t_{50\%Fmax}$** (r = 0,55), while in females between **$t_{50\%Fmax}$** and **$t_{25\%Fmax}$** (r=0,67).

F_{max} value is positively related with force decrement coefficient (**?F, r=0,46 on both sexes**) and rate of this decrement ($\frac{?F}{?t}$ **,** r=0,44 in females and r=0,53 in males). There was no significant correlation between **F_{max}**, and relative coefficients (**?F%** and $\frac{?F_{\%}}{?t}$) describing changes between force variation during 20 s period of MVC.

The results of three endurance trials are negatively related with force decrement and rate of this decrement, what may suggest that subjects with longer endurance times with different resistances (from 25 to 75 % of Fmax) shows smaller changes in above mentioned two variables in test with Fmax. It appears however that both in males and females these relations are very weak and insignificant. There were no significant correlations between endurance times and force decrement and its rate expressed in percentages.

Discussion

The rests of experiment shows that greater diagnostic values during handgrip force variation in isometric contractions have relative variables. In similar way the decrement of muscle force was measured in function of time (Bemben et al. 1996, Wit et al. 1999).

The absolute coefficients of MVC (20 s) are twice as high in males as in females. The **?F** and $\frac{?F}{?t}$ decrease with the decrement of individual strength abilities of subjects. In relative view (**?F%,** $\frac{?F_{\%}}{?t}$) there are no significant sexual differences. Similar results were recorded in other works (Misner et al.1990, Bemben et al. 1996). The levels of decrement are related not with the sex of subject, but the Fmax value. The highest **? F** and $\frac{?F}{?t}$ values were registered in “strongest” while the lowest in “weakest” subjects.

Pitcher and Miles (1997) suggest that the fall in muscle force induced by a continuous MVC is a combination of profound short-term fatigue in anaerobic muscle fibers due to the consumption of their short-term energy supplies, plus a decline in force production by aerobic muscle fibers that is the consequence of hypoxia. As it is commonly known above mentioned processes are related with muscle fibers composition (Ruchlewicz at al. 1996), and mainly depends on blood transportation abilities. The oxygen and energetic substrates supply is different in small and large muscles i.e. in muscles with different cross-section areas; small muscles allows for more effective diffusion in comparison to hypertrophic muscles (Behm and St-Pierre 1998). Probably it is related with blood pressure changes during isometric contraction with different force values (Wright et al. 1999, Franke et al. 2000).

The literature describing the force decrements in MVC with strong cautiousness treat the comparisons of different muscles, even with the use of relative coefficients. It appeared after Rehfeldta et al. (1989) precautions that relation force-endurance during isometric contraction is not biologically constant and cannot be used to all muscles. It was confirmed by Bemben et al. (1996) with determination of force decrement coefficient in healthy male subjects aged 20-74.

The absolute values of force decrement and its rate are significantly correlated with maximal handgrip force, while there was no significant correlation with relative coefficients. It may show that character of force decrement, during longer MVC may be similar in different human muscles. The lack of relation between MVC and endurance time in isometric contraction was found by Chatterjee and Chowdhuri (1991). In contrary to cited authors the results of Wita et al. (1999) who found positive correlation between maximal force and time of MVC of chosen muscle group. It should be also mentioned that in that experiment only the time of MVC was recorded while in presented measurements also the character of force decrement was registered and time of trial was constant.

During tests with resistance set to 75, 50 and 25% $\mathbf{F_{max}}$ until exhaustion the elongation of trial time was register when the resistance was lowered. This effect is obvious and confirmed by many authors (Seals 1993, Ng et al. 1994). The experiments tend to determine the relation between time and load (t=f(F)). Own handgrip force research supplied arguments confirming existence of exponential relation between endurance time and muscle force during isometric contraction (Staszkiewicz et al. 2002). It means, that trials with relatively small load may last very long, while increase of muscle force shortens the endurance time non-linearly to zero. It also worth to underline that sexual differences of $\mathbf{t_{75\%Fmax}}$, $\mathbf{t_{50\%Fmax}}$, $\mathbf{t_{25\%Fmax}}$ decrease with the load decrement. Similar results were presented by Misner et al. (1990), and West et al. (1995).

The relations between Fmax and three endurance tests are described with negative correlation coefficients and in case of both sexes their level is similar. It shows that better results in endurance trials are presented by subjects with lower Fmax. Because of that “weaker” females achieved better endurance coefficients. It appeared also that it is not phenomenon related only with sexual dimorphism, but also with force differentiation; the best results in endurance trial had the weakest subjects (MIII and FIII), while the worst subject from the strongest groups. It confirmed known ontogenetical principle (Szopa 1985, Szopa et al. 1996), which state, that higher level of developed feature causes greater progressive and involutionary dynamics.

It may be stated that in experiments based on isometric contraction, three trial times ($\mathbf{t_{75\%Fmax}}$, $\mathbf{t_{50\%Fmax}}$, $\mathbf{t_{25\%Fmax}}$) may be treated as endurance measure, and depends on absolute muscle force. Because of that the use of constant criterion (for instance 50% of Fmax) does not guarantee comparable experiment circumstances. Subject pressing with 500N has to resist in endurance test to 250N, while subject with Fmax=200N only to 100N. However both of them resist to 50% of Fmax but the absolute values are significantly different. These values decide about veins and arteries pressure what is followed by decreased oxygen and energetic substrates transportation. The comparison of results, based on the isometric contraction in subject with different Fmax values seem to be useless, because stronger subject acquire worse results, and it may lead to conclusion that unhealthy people show better endurance that healthy (Musur 1974). It seems that control research may be conducted with individual subjects or with groups presenting similar level of Fmax.

The presented above results showed that trial with load equal to 75, 50 and 25%F_{max} are positively correlated. It may suggest that choice of load may be voluntary. However, it appeared that trial with 25% Fmax were similar in stronger males and weaker females and endurance times were close to 8 min. and result was dependent strongly on motivational factors than force parameters. On the other side high loads (**75%F_{max}**) cause blood circulation and pressure worsening that may lead to dangerous circumstances, especially in isometric contractions of large muscle groups.

The relationships between variables describing Fmax and lower force contractions (**$t_{75\%Fmax}$, $t_{50\%Fmax}$, $t_{25\%Fmax}$**) allows to state, that changes in force levels during such a contractions do not reflect the strength endurance. The correlation coefficients show low and negative relationship between discussed variables. It was possible to presume that subject with high force decrement in MVC would achieve shorter endurance times in typical endurance tests with the lower than MVC loads, what may suggest some similarities between these tests. The separation of subjects with high and low level of MVC showed different results - only **$t_{75\%Fmax}$** is significantly correlated with force decrement variables in MVC, while in the weakest groups (FIII and MIII) correlation coefficients were even positive. These groups, with similar force decrement in MVC trial, achieved in submaximal trial (**$t_{75\%Fmax}$**) the best results. Long endurance times in **$t_{75\%Fmax}$** trial were caused probably by good blood circulation quality in subjects which performed with relatively low loads.

The trial of long-term MVC was not then valid diagnostic tool in muscle endurance evaluation. It may be rather indirect method of determination of fast and slow fibers composition in researched muscles, what was confirmed by Viitasalo and Komi (1978).

Conclusions

The acquired results and literature data allowed formulating following conclusions:

1. Maximal handgrip force is negatively correlated with endurance time, and subjects with the lowest Fmax showed the best results.
2. The results of handgrip endurance in isometric contraction may not be used as objective coefficient of muscle endurance, because depend in great degree on Fmax of subjects.
3. The endurance diagnosis in isometric contractions may be reasonable only in temporal control of individuals or observation of groups of subjects with similar Fmax level. Suggested load should be equal to 50% of Fmax.
4. Acquired results who, that better results achieved be females in endurance testing, are not caused by sexual dimorphism but their lower level of Fmax.
5. Force changes during trials based on long-term MVC are not correlated with endurance tests. It may be rather treated as indirect method of determination of fast and slow fibers composition in researched muscles

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