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QUANTITATIVE INDICATORS OF UPPER EXTREMITY MUSCLE POTENTIAL IN INDIVIDUALS WITH SPINAL CORD INJURY – PARAPLEGIA: A PILOT STUDY

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SUMMARY

This study aimed to present quantitative indicators of muscle potential of the upper extremities in persons with spinal cord injury – paraplegia. For the purposes of the research, the isometric dynamometry method and standardized handgrip test were applied. A total of 15 males participated in the study, of which 12 subjects had complete and 3 subjects had incomplete spinal cord injury, mean age 46.66 ± 8.28 years. They have undergone a rehabilitation phase and at least 12 years have passed since the spinal cord injury. All subjects moved using standard mechanically powered wheelchairs and all were right-handed. Maximum values of muscle potential (maximal muscular force of the left hand and the right hand expressed in N, time aspect of force manifestation at 50% of maximum expressed in s, endurance in force expressed in Ns, as well as summary values of muscle potential) and functional dimorphism were analyzed. All results are presented in absolute and relative values of muscle potential. The maximum handgrip of the left hand was 448.79 ± 85.58 N, and 490.55 ± 79.06 N for the right. The research results show that the summary value of the muscle potential of the hand strength was 939.34 ± 163.21 N, whereas the relative value was 11.30 ± 2.49 N/kg. The functional dimorphism for the maximum handgrip between the non-dominant and dominant hand was 0.912 ± 0.05. The summary value of the muscular potential for endurance at 50% of the maximum was 28004.67 ± 11233.66 Ns, while the relative value was 334.82 ± 129.65 Ns/kg. The functional dimorphism for of endurance in force was 0.793 ± 0.11. Based on the results, changes in functional independence and motor abilities of persons with spinal cord injury during and after rehabilitation could be monitored.

Key words: spinal cord injuries, handgrip, muscle potential, functional dimorphism, endurance in force

INTRODUCTION

Paraplegia represents impairment or loss of motor and sensory functions in the thoracic, lumbar, or sacral segments of the spinal cord due to a lesion of neural elements in the spinal canal. In paraplegia, the function of the upper extremities is preserved and depending on the neurological level and completeness of the lesion, the function of the trunk, lower extremities and pelvic organs may be impaired. The most intensive recovery occurs in the first few months after the spinal cord lesion, after which the dynamics are maintained or slowed down (Jović, 2011). Baldi et al., (1998) state that total muscle mass decreases by 9.5% in the first 6 months, while lower extremity muscle tissue decreases by 15.1% in the first year after spinal cord injury (Wilmet et al., 1995). People with spinal cord injury (hereinafter referred to as SCI) lead a sedentary lifestyle; their needs, abilities and limitations change over time and most are physically inactive (Anneken et al., 2010).

In the rehabilitation phase, ie the so-called mobilization phase, people with SCI are trained for the use of wheelchairs, for which they need adequate strength, endurance and power of the muscles of the upper extremities and torso. It should be noted that spinal cord injuries above the twelfth thoracic vertebra lead to impaired postural balance in the sitting position, which increases the load on the upper extremities (Zoeller et al., 2005). In addition to the basic activities of moving a wheelchair forward, back, right and left, transfer training plays an important role. It involves moving from the bed to the wheelchair and vice versa, then moving to a chair, on a mat, to the toilet, in a car, opening and closing the door, lifting objects off the floor and so on (Jovanović et al., 2016). This is followed by training in mastering the architectural characteristics of the surrounding in which a person with SCI lives, which relate to driving on an oblique plane – ramps, entering and exiting elevators, as well as moving in public buildings and public transport. All of the above is especially important when rehabilitation is completed, upon return to the family and social environment (Jović, 2011). Functional independence and performance of daily activities will depend on the level of motor abilities (Ribeiro Neto et al., 2017).

However, reduced physical capacity is a common feature of all individuals who have experienced spinal cord injury, and is the result of a loss of motor control, muscle atrophy, and additional inactivity (Martin Ginis et al., 2010). The ageing process itself can accelerate and thus intensify changes in the musculoskeletal system resulting from cumulative stresses, especially the upper extremities and the shoulder girdle. In addition, atrophy due to inactivity occurs much faster than atrophy that occurs with ageing. Due to inactivity, the volume of movement in the joints and the elasticity of the soft tissues decrease over time, the need for energy is reduced, and the reduced muscular work weakens the heart strength (Jovanović et al., 2016).

The mobility of people with SCI is also influencedby the presence of secondary complications, secondary urinary infections, muscle spasms and pressure ulcers (Milićević et al., 2012). Moreover, people who lead a sedentary lifestyle are more likely to gain weight, especially people with SCI, which is an aggravating factor in everyday functioning (deGroot et al., 2010). Overall, reduced self-care ability associated with a higher upper extremity load increases physical effort, causing fatigue and distress (Janssen et al., 1996).

One of the focuses of the research, which is conducted in order to improve the quality of life of people with SCI, is to find ways to reduce physical stress during functional activities and to preserve upper-limb health (Chow & Levy, 2011). Studies in the field of biomechanics contribute to the understanding of the factors responsible for producing the muscular strength of preserved muscles, in terms of increasing the efficiency of wheelchair mobility (van der Woude et al., 2001). The analysis of kinematic and kinetic variables determines the most loaded joints and segments of the musculoskeletal system of persons with SCI (Larraga García et al., 2019). Then, there are dynamometric methods that that are used for examining the strength of postural muscles, as well as for the evaluation of the muscle strength of the upper extremities (Sisto & Dyson Hudson, 2007).

Assessment of maximal grip strength has proven to be a good indicator of the total strength of the upper extremities (Wang et al., 2018) and the overall neuromuscular system (Chan et al., 2008). A more recent study shows that the measurement of the maximum handgrip and the relationship between the non-dominant hand and dominant hand can predict disability in everyday activities during the ageing process (Mc Grath et al., 2020).

Assessment of the muscle force of the finger flexors by isometric dynamometry method is applied to test the contractile abilities of the hand muscles. This simple and non-invasive test is an indicator of qualitative and quantitative muscle functions. By using modern testing devices with a state-of-the-art hardware-software system, which uses very high-sensitivity tensiometric probes, it is possible to record force change in a unit of time of over 100 MHz/s. Such a speed of data acquisition provides an opportunity to analyze the record of the change in force in a unit of time concerning the very structure of the mechanical manifestations of the observed contraction. Therefore, it is possible to analyze all the mechanical characteristics of the force record (Dopsaj et al., 2009). Thus, using this test, data on the level of development of the maximum force (Maximal grip strength – F_{max}) or explosive force (Rate of Force Development – RFD) of the tested muscles can be obtained, as well as data on the capacity to maintain a given level of force (Isometric endurance), usually at 50% of maximum, on the time aspect of force manifestation in a certain percentage (usually at 50% – $tF_{max}50\%$) and the time required to exhibit a specific level of explosive force ($tRFD_{max}$). From the obtained data, summary ($F_{max}SUM$) or relative values can be further calculated by the classical or allometric method (relative value of maximal isometric handgrip force – $F_{max}REL$), but also functional dimorphism and force impulse (ImpF) (Ivanović & Dopsaj, 2012).

The results of an examination of various parameters obtained by the method of isometric dynamometry show that this method can be used both in young and healthy persons (Kljajić et al., 2012) and in the elderly (Trajkov et al., 2018).

The subject of this study is an examination of the muscle potential in individuals with SCI. Namely, the basic function is to provide a muscle contraction, that is, to be activated from the state of physiological tone into some desired tone, which depends on the intensity of the internal voluntary or external involuntary stimulus. Potential, at the level of physical manifestation of muscle tone, is measured over the realized mechanical magnitudes of the analogue output of the achieved tone and is expressed in physical quantities of the same (Dopsaj et al., 2002).

This pilot study aims to present quantitative indicators of upper extremity muscle potential in individuals with SCI – paraplegia. The results can be used for further research in a population of persons with different levels of spinal cord injury, as well as in other persons with disabilities who use wheelchairs.

RESEARCH METHOD

Subject

The sample consisted of a total of 15 males, aged between 30 and 60, who had a spinal cord injury – paraplegia and who were wheelchair users. The criterion was that the subjects had undergone a rehabilitation phase, had no injuries or pain in the upper extremities lately, and that they were not involved in any sport regularly. Subjects were beneficiaries of the Home for Adult Disabled Persons in Zemun, they were familiar with the testing conditions and voluntarily participated in the research. First, they filled out a general questionnaire designed for general research purposes, and then the measurement was conducted. The basic anthropometric indicator – body height (BH, cm) was taken from the medical records of the participant, while the last measurement of body weight (BM, kg) was taken as a valid data. All subjects stated that their right hand was dominant. Characteristics of the subjects related to age, time after injury, a spinal cord injury level and completeness of injury (by ASIA scale) are shown in Table 1. Additionally, Table 1 shows anthropometric indicators of body height, body weight and body mass index (BMI).

Table 1. *Characteristics of subjects in relation to age, spinal cord injury and anthropometric indicators*

	M	SD	cV%	Min	Max
Age (years)	46.66	8.28	17.74	32.4	59.9
Time after injury (years)	21.27	8.69	40.84	12.3	44
BH (cm)	179.79	6.96	3.87	168	193
BM (kg)	84.64	12.10	14.30	63	103
BMI (kg/m^2)	26.20	3.66	13.97	22.10	34.60
Level of injury n (%)	Thoracic 9 (60%)	Lumbar 6 (40%)			
ASIA n (%)	A (complete) 12 (80%)	B (incomplete) 2 (13.33%)	C (incomplete) 1 (6.67%)		

The research was carried out following the conditions of the Declaration of Helsinki, with the approval and consent of the Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade (484-2).

METHOD

A test for the evaluation of the muscular force of the finger flexors – the isometric dynamometry method was used in the study (Dopsaj et al., 2011). Testing procedure: after a 5 minutes self-warming up of the general character, the testing procedure was explained to each participant, after which the participant made two trial hand grip attempts (with left and right hand) to perform specific warm-ups. After a 5-minute break, the participant proceeded to the test protocol. First, two alternating measurements of the maximum handgrip of both hands (first dominant, then non-dominant hand) were performed with a break of at least 1 minute between each attempt to test one hand. After calculating the force values for each hand at the level of 50% of the maximum ($F_{50\%L}$ for the left arm and $F_{50\%R}$ for the right arm), a rest of 10 minutes was provided. Then, the measurement of the force manifestation capacity (endurance of the expression of isometric muscle force) was conducted, that is the time interval during which the subjects could maintain the required level of atthe 50% of the maximumlevel. Testing was performed in a sitting position, in a wheelchair (Figure 1).

Figure 1 – Muscle force testing – isometric dynamometry method

Variables

- *Absolute values of muscle potential:*

- A maximal muscular force of the left hand and the right hand ($F_{maxL}$and F_{maxR}), expressed in newtons (N);

- The time aspect of the manifestation of a given percentage of force:

- Time of carrying out the muscle force of handgrip at 50% of the maximum handgrip value with the left and right hand – $tF_{50\%L}$ and $tF_{50\%R}$, expressed in seconds (s).

- Endurance of the force:

- An impulse of the muscular force of the handgrip with the left and right hand at 50% of the maximum handgrip force – $I_{mp}F_{50\%L}$ and $I_{mp}F_{50\%R}$, expressed in newton-second (Ns).

- *Total muscle potential – hand strength* refers to the sum of the maximum left and right hand grip force expressed in newtons (N) – $F_{max}SUM$, where $F_{max}SUM=F_{max}L+F_{max}R$.

- *Total muscle potential – the time of maintaining the given force*refers to the sum of the time of maintenance of a level of muscular force at 50% of the maximum value of handgrip of the left and right hand, expressed in seconds (s) – $tF_{50\%}SUM$, where $tF_{50\%}SUM= tF_{50\%}L+ tF_{50\%}R$.

- *Total muscle potential – endurance* refers to the sum of the absolute values of the endurance in the force – the impulse of the muscular force of the handgrip of the left and right hand at 50% of the maximum force of handgrip, expressed in newton-second (Ns)– $_{imp}F_{50\%}SUM$, where $_{imp}F_{50\%}SUM={}_{imp}F_{50\%}L+{}_{imp}F_{50\%}R$.

- *Relative values of total muscle potential:*

- Relative hand strength – $F_{rel}SUM$, expressed in newton per kilogram of body weight (N/kg), where $F_{rel}SUM= F_{max}SUM/BM$.
- Relative time of maintaining the level of muscle force at 50% of the maximum value of the left and right handgrip per kilogram of body weight– $tF_{50\%}SUM_{rel}$,

expressed in seconds per kilogram of body weight (s/kg), wheret $F_{50\%}SUM_{rel}$ = $tF_{50\%}SUM/BM$.

- Relative value of muscle endurance – $_{imp}F_{50\%}SUM_{rel}$, expressed in newton-seconds per kilogram of body weight (Ns/kg), where $_{imp}F_{50\%}SUM_{rel} = {}_{imp}F_{50\%}SUM/BM$.

- *Functional dimorphism*is defined as the index relation of the analyzed force characteristics, the time of expression of a given force and the force impulse of the non-dominant (left) and dominant (right) hands of the subjects:

- Relationship between the maximum muscle handgrip force of the non-dominant and dominant hand – $F_{max}L/R$;
- Relationship between the time of realization of the muscular force of the handgrip at 50% of the maximum of the non-dominant and dominant hand – $tF_{50\%}L/R$;
- Relationship between the absolute value of the impulse of muscle force at 50% of the maximum of the non-dominant and dominanthand – $I_{mp}F_{50\%}L/R$.

Statistical data processing

All results were analyzed using the descriptive statistical method, where the following were calculated: measures of central tendency (mean value of a variable – arithmetic mean) measures of variability (standard deviation – SD, coefficient of variation – cV%), range limits (minimum – Min andmaximum – Max). Statistical data processing was performed using the software package Exce 2003 (Microsoft®Office Excel 2003).

RESULTS

Table 2 shows the results of the descriptive statistical measure of the examined variables. The results show that the coefficient of variation, as a basic measure of estimating the homogeneity of the raw data, ranged from 16.12% to 42.95%. For more than half of the variables the value of the coefficient of variation is in the zone less than 30% and less in the zone of moderately homogeneous results (the zone between 30-60%), so these data can be interpreted at the population level as generally reliable. The maximum handgrip averaged 448.79 ± 85.58 N for the left hand and 490.55 ± 79.06 N for the right hand. Concerning the endurance at 50% of the maximum force of the handgrip, and presented as a force impulse, our subjects had values for the left hand of 12329.06 ± 5295.52 Ns on average and 15675.62 ± 6097.96 Ns for the right hand.

Table 2. *Results of basic descriptive statistics of variables of muscle force, time of manifestation and endurance in force*

	M	SD	cV%	Min	Max
F_{maxL} (N)	448.79	85.58	19.07	258	637
F_{maxR} (N)	490.55	79.06	16.12	284	639
$F_{50\%maxL}$ (N)	224.39	42.79	19.07	129	318.50
$F_{50\%maxR}$ (N)	245.28	39.53	16.12	142	319.50
$tF_{50\%L}$ (s)	54.55	15.69	28.75	28.25	88.19
$tF_{50\%R}$ (s)	63.72	19.13	30.02	25.52	98.71
$I_{mp}F_{50\%L}$ (Ns)	12329.06	5295.52	42.95	7073.82	28088.52
$I_{mp}F_{50\%R}$ (Ns)	15675.62	6097.96	38.9	7043.52	30758.27

Summary and relative indicators of total muscle potential are shown in Table 3. Summary indicators refer to the sum: the maximum muscular force of left and right handgrip, then the time of maintaining muscle force level at 50% of the maximum value of the left and right handgrip and strength endurance – the impulse of a muscular force of left and right handgrip on 50% of the maximum handgrip force. Relative indicators of total muscle potential are represented by absolute values in relation to a kilogram of body weight. The table shows that the relative strength of the hands expressed per kilogram of body weight was 11.30 ± 2.49 N/kg, while the relative value of muscle endurance expressed per kilogram of body weight was 334.82 ± 129.65 Ns/kg.

Table 3. *Results of descriptive statistics of total muscle potential of hand – summary and relative indicators*

	M	SD	cV%	Min	Max
$F_{max}SUM$ (N)	939.34	163.21	17.38	542	1276
$tF_{50\%}SUM$ (s)	118.27	33.96	28.71	53.77	184.46
$_{imp}F_{50\%}SUM$ (Ns)	28004.67	11233.66	40.11	14148.40	58846.78
$F_{rel}SUM$(N/kg)	11.30	2.49	22.07	6.53	15.81
$tF_{50\%}SUM_{rel}$ (s/kg)	1.42	0.44	31.17	0.72	2.18
$_{imp}F_{50\%}SUM_{rel}$ (Ns/kg)	334.82	129.65	38.72	179.64	571.33

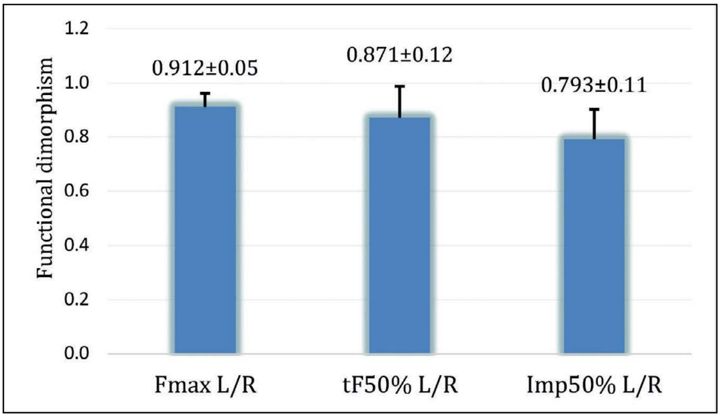

Figure 2. Functional dimorphism of the analyzed force characteristics, time of manifestation of a given force and force impulse

Figure 2 shows the index relation (functional dimorphism) of non-dominant (left) hand and the dominant (right) hand of the subjects in relation to maximum muscle force of handgrip, time of realization of muscle force of handgrip 50% of maximum and the absolute value of muscle force impulse 50% from the maximum.

DISCUSSION

The morphological characteristics and motor abilities are mainly determined by an individual set of endogenous and exogenous factors. Science has achieved significant results in discovering, studying and developing human capabilities, whereas improving the functioning of people with disabilities is an important goal of rehabilitation. Good knowledge of morphological changes that occur as a result of spinal cord injury is the basis of knowledge for those characteristics that we can influence, and these are primarily the motor abilities of the upper extremities. Their testing and measurement give us a starting point for examining the current state, as well as the changes that may occur either by additional inactivity or application of some form of physical activity. The study aimed to present quantitative indicators of upper extremity muscle potential in persons with SCI – paraplegia using a test for the evaluation of the muscular force of the finger flexors – the isometric dynamometry method.

Our subjects were males, who had a body mass index of 26.20 ± 3.66 kg/m^2 (Table 1). According to the classification of the World Health Organization, this classifies them in the group of "overweight" people, because the BMI ranges between 25 and 29.9 kg/m^2 (WHO: BMI Classification, 2020). Because people with SCI lead a sedentary lifestyle, they could be expected to have higher BMI values, as the time after injury averaged 21.27 ± 8.69 years. However, one should bear in mindthe fact that BMI increases in people with spinal cord injury from 2.8 to 3.4 units every 6 years (deGroot et al., 2010). By comparison, in a healthy human population, ageing increases BMI by 1 unit every 5 years (Nooyens et al., 2009). For our research, these data are of great importance because additional weight represents a greater load on the joints of the upper extremities. As far as the wrist joints are concerned, the greatest loads are in the propulsion phase, which starts from the beginning of pushing the wheels and lasts until the phase of returning the hands. The efficiency of wheelchair movement will depend on the mobility of these joints, the muscles that participate in the stabilization and compression of the hand, as well as the rolling resistance (Aleksandrović et al., 2016).

The maximum value of handgrip in our subjects was 448.79 ± 85.58 N and 490.55 ± 79.06 N for the left and the right hand, respectively. The difference in favour of the right hand was expected because all subjects reported the right hand as dominant (Table 2). If we compare our results with the results of a 2015 study where male subjects had maximum handgrip values of 560.9 ± 91.9 N and 620.6 ± 101.9 N for the left and the right hand, respectively, we can find that our subjects had a maximum handgrip less by 25.2% for the left hand, and 26.5% for the right hand (Trajkov et al., 2015). These subjects, like the ones from our research, were not systematically engaged in any physical activity and were overweight, given that their BMI was 26.7 ± 3.15 kg/m^2. The only difference was that they were younger than our subjects by an average of 8.48 years.

Comparing our results with the normative data of other populations aged 30 to 60, we come across some differences. Thus, adult male Korean subjects have significantly weaker handgrip. According to the data, depending on age, the average values of the handgrip for the right hand ranged on average from 40 kg to 42 kg (392 N to 411 N) and from 39 kg to 41 kg (382 N to 402 N) for the left hand (Lim et al., 2019). In Brazilian subjects, 42.8 kg (419 N) was found for the right hand, whereas 40.9 kg (401 N) was found for the left hand on average (Schlüssel et al., 2008). The average value of the right handgrip in Greek male subjects of similar age with lower extremity injury was 123 lbs (547 N), while for the left hand it was 111 lbs (493 N) (Mitsioniset et al., 2008).

The research published in 2018 (Marković et al.) shows the results of the maximum handgrip closer to our results (520.5 ± 107.4 N for non-dominant and 557.6 ± 112 N for dominant hand). The finding would indicate that our subjects were less successful in this test by an average of 14.8%. This result is understandable since subjects were also male, aged between 35 and 49.9 years, while the average age in our study was 46.66 years.

Most activities of everyday life require effort over a certain period. In addition to the maximum muscle strength of the handgrip, as an indicator of the function of the upper extremities, measuring the static endurance of the flexor muscles of the hand and fingers can provide a complete picture of hand function and overall functional capacity of healthy individuals. Furthermore, the examination of these variables in people with SCI is important in order to monitor changes in the musculoskeletal system, especially since it is known that higher muscle strength is associated with higher aerobic strength and endurance in people with paraplegia (Zoeller et al., 2005).

As in most previous studies that examined endurance as a measure of time, test protocols were based on maintaining maximum or submaximal levels of muscle contraction (30%, 50%, or 80% of Fmax). In previous studies, it has been observed that the endurance time increases with a decrease in a given submaximal force, which is also true for absolute and relative indicators of force impulse (Kljajić et al., 2012). Staszkiewicz et al., (2002) concluded that a static test with a load set at 50%

of maximum force (F_{max}) is the most important description of endurance in isometric submaximal contractions.

The results of our research, which refer to the time aspect of the endurance of a given level of force of 50% of the maximum, show that the subjects of the current study were more successful in relation to the general population. Namely, in our subjects, the endurance in force at 50% of the maximum was 54.55 ± 15.69 s for the non-dominant hand and 63.72 ± 19.13 s for the dominant one (Table 2). These results were compared with the research results from 2012, which included subjects twice younger than ours and who had a time of manifestation of force at 50% of the maximum of 49.03 ± 11.2 s for the non-dominant hand and 55.12 ± 9.69s for the dominant one (Kljajić et al., 2012). Therefore, it was noticed that our subjects had higher endurance because they maintained the required level of force longer, 5.52 s with the left hand and 8.6 s with the right hand, which is on average 12% longer.

Very similar results were presented in a study published earlier (Dopsaj et al., 2011). The main difference is that the subjects were students of the Criminal Police Academy who are considered to have a significant level of motor skills. The endurance of our subjects was higher by 14%, both concerning the left and the right hand, from the time aspect of endurance in force to 50% of the maximum. These results show greater endurance in subjects with SCI, which may be related to the fact that endurance is affected by repetitive movements of lower intensity and longer duration, such as wheelchair movement.

The average value of the force impulse, which is also an indicator of endurance in force, in our subjects was 12329.06 Ns for the left hand and 15675.62 Ns for the right hand. However, the relationship between the left and right hand – the index of functional dimorphism of endurance in force was 0.793, which means that the left hand makes 79.3% of the value of endurance of the right hand (Figure 2). This difference is unusual because our subjects reported that they had no musculoskeletal problems with the upper extremities, and what they all had in common was that they were wheelchair users, which requires equal use of both upper extremities. Chatterjee & Chowdhuri (1991) stated that in their subjects, the dominant arm also had greater endurance than the non-dominant one and that this did not always have to be the rule.

Moreover, endurance can be tested by both repeated dynamic contraction as well as repeated contraction on an isokinetic dynamometer. In this way, the results of our subjects might be clearer, since the kinematics of the wheelchair has a propulsive phase (repulsion phase) and a retropulsive phase (return phase to the beginning), where the force of handgrip and relaxation is manifested in a short period. For example, the retropulsive phase, which lasts from the moment the hand separates from the wheel frame and returns to the starting position for a new push, lasts on average 65-75% of the entire propulsive process, which is the period of relaxation of the muscles involved in the handgrip (Aleksandrović el al., 2016).

By comparing the maximum value of the left and right handgrip, ie non-dominant and dominant, it can be noticed that the value of functional dimorphism is 0.912 ± 0.05, which means that the right hand is stronger than the left by 8.8% (Figure 2). This result confirms the well-known fact that the dominant hand is about 10% stronger than the non-dominant one (Kolev & Halacheva, 2015).

The total muscle potential of hand strength, ie muscle force of the left and right handgrip was 939.34 ± 163.21 N. When we relativize it, we get that per kg of body weight the muscle potential of hand strength was 11.30 ± 2.49 N/kg. Concerning the time of maintaining the given force, the relative values averaged 11.42 ± 0.44 s/kg. The total muscular potential of endurance, which refers to the sum of absolute values of endurance in force – the impulse of the left and right handgrip at 50% of the maximum force of handgrip, was 28004.67 ± 11233.66 Ns, while relative values were 334.82 ± 129.65 Ns/kg (Table 3).

Muscle strength and endurance are two different dimensions of the contractile ability of skeletal muscles. Both components can be significantly impaired in people with SCI. Therefore, it is essential to develop the endurance measurement and analysis methods in addition to traditional tests of maximal strength. It is also essential to include endurance measurements in a standard assessment of upper extremity functionality in people with paraplegia. It would be useful to examine the endurance of people with paraplegia in relation to physical activity or some other parameters in future studies.

CONCLUSION

This study aimed to show quantitative indicators of the muscle potential of the upper extremities in people with spinal cord injury – paraplegia. The research results showed that the maximum handgrip of the left hand was 448.79 ± 85.58 N and 490.55 ± 79.06 N for the right hand. The summary value of the muscle potential of the hand strength was 939.34 ± 163.21 N, whereas the relative value was 11.30 ± 2.49 N/kg. The functional dimorphism for the maximum handgrip between the non-dominant and dominant hand was 0.912, ie the right hand was 8.8% stronger than the left hand. The summary value of the muscular potential for endurance at 50% of the maximum was 28004.67 ± 11233.66 Ns, while the relative value was 334.82 ± 129.65 Ns/kg. The functional dimorphism for of endurance in force showed that the right hand had a higher endurance than the left hand by 20.7% (the index of functional dimorphism was 0.793).

In this study, the relative values of upper extremity muscle potential for people with SCI were presented for the first time. Also, functional dimorphism in wheelchair users was examined for the first time, using the isometric dynamometry method. The obtained results could further serve the purpose of measuring these abilities in persons with different levels of spinal cord injury, as well as in other conditions where wheelchairs are used for mobility. Also, changes in functional independence and motor abilities during and after rehabilitation, the impact of physical activity and sports, but also inactivity could be monitored, as well.

Study limitations relate to the sample size. Subsequent research should include female subjects, as well as with subjects who have other pathological conditions, and use mobility aids.

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