ORIGINAL PAPER

TRENDS in Sport Sciences 2013; 2(20): 89-94. ISSN 2299-9590

Spirometric and ergospirometric evaluation of wheelchair rugby players

KATARZYNA DOMASZEWSKA, ŁUKASZ SZYMCZAK, JAKUB KRYŚCIAK, BARBARA POSPIESZNA, MARIA LAURENTOWSKA

Introduction. Cervical spinal cord injury is one of most common human body deficiencies. Quadriplegia affects not only the mass of paralyzed muscles, but also disrupts physiological exercise adaptation mechanisms. One of the few sports suitable for individuals with cervical spine impairment is wheelchair rugby. Professional athletes display a higher exercise capacity than untrained people with a similar degree of spinal damage. The reduction of aerobic capacity in individuals with cervical spinal cord injury is multifactorial. In addition to cardio-pulmonary mechanisms limiting the exercise capacity, the decrease in active muscle mass leads to the rapid development of tissue hypoxia. Material and Methods. 14 members of the Polish National Wheelchair Rugby Team were recruited for the study. The male players aged 20-40 years with cervical spinal cord injuries underwent spirometric and ergospirometric tests. Results. The mean values of spirometric parameters were: VC 3.9 \pm 0.71 l (71.3% predicted), ERV 0.9 ± 0.33 l (60.7% predicted), VE 12.6 \pm 6.34 4 l/min, Bf 18.3 \pm 4.72 l/min, VT 0.7 \pm 0.20 l, FVC 4.05 \pm 0.69 l/min (76.3% predicted), FEV $_{1.0}$ /FVC 92.2 ± 7.10% (113.45% predicted), MVV 141.7 \pm 24.59 l/min (97.15% predicted). The mean value of peak oxygen consumption during exercise was 1.31 ± 0.30 l/min (17.8 ± 4.99 ml/kg/min) achieved within 11.8 \pm 3.51 min. The mean maximal workload was 42.5 \pm 13.99 W. During the test only 10 players reached the anaerobic threshold (AT) intensity. The mean workload at AT was 36 ± 10.62 W, and VO, max at AT was 0.9 ± 0.26 l/min (15.5 ± 4.17 ml/kg/min). Conclusions. The results of spirometric tests indicate the presence of mild and medium restrictive pulmonary changes in 8 out of the studied players of the Polish National Wheelchair Rugby

Corresponding author: K. Domaszewska, e-mail: kowalczyk@awf.poznan.pl University School of Physical Education, Poznań, Department of Physiology, Poland

Team. The physiological parameters obtained during the exercise test indicate a higher aerobic capacity of surveyed athletes in comparison with untrained quadriplegics.

KEY WORDS: quadriplegia, maximal oxygen uptake, ergospirometry, spirometry.

What is already known on this topic?

People with cervical spinal cord injuries usually demonstrate reduced values of spirometric parameters and low physical efficiency.

Introduction

Cervical spinal cord injury is one of the most common injuries of the human body. According to Kiwerski, 25-35 people per 1 m. of the general population suffer from such injuries. It should be also mentioned that men tend to suffer more often from cervical spinal cord injuries than women. According to Tasiemski, the number is 5-6 times higher, and only few individuals return to practicing their professional or sports activity from before the injury [1, 2, 3].

Received: 11 February 2013 Accepted: 29 April 2013

Tetraplegia is the state after spine damage at the cervical level. Its consequence is handicap or the lack of movement in the sphere of four limbs and the torso. In order to determine the level of damage, apart from diagnostics tests, specific neurological tests are used. In case of spine damage following a spinal cord injury, changes occur at the site of the injury but also spread a few sections up and down the spine. Therefore, it is possible that two individuals suffering from the injury of the same spinal section have two different clinical pictures [1, 4]. Depending on the mechanism of the injury a clinical picture may include flaccid or spastic paralysis of skeletal muscles, disorder or the lack of all types of sensation, or disorder or the lack of movement. The impairment of muscle function also hinders activities of daily living such as locomotion [1, 4, 5].

Tetraplegia not only leads to a decrease in the mass of paralyzed muscles but also disturbs the physiological mechanisms of adjustment to physical exercise through restriction of efficiency of the circulatory, respiratory or nervous system.

Wheelchair rugby is one of few sports for people who suffer from cervical spinal cord injuries. The sport, which appeared in Poland in 1997, is currently a Paralympic discipline. In 2010 the Polish Paralympic wheelchair rugby team won the eighth place during the World Cup in Vancouver, Canada [2, 6, 7]. It is obvious that competitive parathletes have a better functional capacity than their able-bodied counterparts who do not practice any sport. Wheelchair rugby is a discipline where endurance and speed are important. Therefore a good wheelchair rugby player has to display high aerobic capacity involving ATP for muscle work coming mainly from mitochondrial metabolism. The reduction of aerobic function in individuals suffering from cervical spinal cord damage is of multi-factorial character. The muscle pump decreases because of lower limb paralysis and, partially, upper limb paralysis. Similarly, the venous return of blood to the heart becomes insufficient. According to the Frank-Starling law of the heart this causes a decrease in myocardial tension, stroke volume, cardiac output or blood pressure. The decreasing hemodynamic parameters of the heart are different from those of healthy people. This is caused by the lack of influence of the sympathetic nervous system on the cardiac muscle, state of blood vessels or the secretory activity of endocrine glands. Exercise heart rate is the effect of slowing down of the vagus nerve or the influence of humoral factors [8, 9, 10]. As far as patients with cervical spinal cord injures are concerned, their resting values and stress of cardio-respiratory indicators and blood chemistry differ from those of able-bodied individuals as well as from amputees with preserved mechanisms of stimulation of the sympathetic nervous system [11].

Paralytic post-traumatic changes occur within the respiratory muscles. The lack of possibilities of increasing the tidal volume is compensated for more frequent breaths at rest. The respiratory compensation mechanisms escalate during exercise and lead to fast tiredness of respiratory muscles and exertional dysponea [24].

The weakness of respiratory muscles has an effect on coughing and impossibility to remove secretions from the bronchial tree. This leads to frequent infections that repeatedly contribute to the death of a patient. The degree of respiratory system function can be determined by a typical spirometry examination.

The cardio-respiratory components which limit exercise options but also decrease active muscle mass with simultaneous metabolic disorders contribute to the fast development of tissue hypoxia. It has been stated that the work of muscles of patients who suffer from spinal cord injuries, recruits almost 100% of white fibers as well as FTa and FTb, excluding the recruitment of red fibers. This appears through the fast development of fatigue. The causes of exercise intolerance can be determined by ergospirometric examination. This examination is comparatively safe; however, considering the fitness of examined disabled subjects, especially non-training ones, it may be difficult to carry out [22, 23].

Materials and Methods

14 male players of the Polish Paralympic wheelchair rugby team aged 27-41 years were examined. All the players suffered from cervical spinal cord damage. They arrived one day before the tests. Stress tests were carried out in the morning, two hours after a light meal. In order to eliminate factors affecting the resting physiological indices the athletes arrived in the gym using elevators. They were also informed about the purpose and methodology of the study. The anthropometric data of the examined players is shown in Table 1.

Spirometric examination

The spirometric examination was carried out with the use of a Cosmed spirometer, which allowed marking the subjects' static and dynamic parameters of the respiratory

Group [n=14]	Age [years]	Body height [cm]	Body mass [kg]	BMI [kg/m ²]	Training experience [years]	Number of years after injury [years]	Training beginning [years]
Mean	34.36	182.29	72.21	21.87	8.36	11.93	3.57
SD	14	22	41	17	14	4.57	2.17
Min.	27	171	59	16.1	1	2	1
Max	41	193	99	33.1	15	20	8

Table 1. Mean values of anthropometric parameters and injury data

Discussion

The spirometric and ergospirometric tests in the context of functional analysis of subjects always aim at the diagnostics of effectiveness of the leading training or rehabilitation process. They objectively indicate factors that restrict respiratory abilities and as well oxygen consumption of muscle.

system: VC – vital capacity; ERV – expiratory reserve volume; VE – lung ventilation; Rf – breath frequency; VT – tidal volume; FVC – forced expiratory capacity; $FEV_{1.0}/FVC$ – Tiffeneau index; MVV – maximum voluntary ventilation.

Ergospirometric examination

The marking of VO_2 max and AT throughout the exercise test in a continuous way with a Jaeger Oxycon Mobile ergospirometer allowed recording of cardio-respiratory indices: HR – heart rate; VO_2 – oxygen uptake; VE – lung ventilation.

The exercise test was performed on a manual Monark Cyklo-Ergometr. Its design and assembly allowed for individual adjustment according to subjects' functional capabilities. The attachment of the ergospirometer did not limit the patients' movement or respiratory abilities.

Every participant performed the test with an incremental load starting from 10 W (60 rpm) and increasing for 10 W every 3 minutes until obtaining maximum individual effort or refusal (Fig. 1).

Results

The spirometric test results are shown in Table 2. Table 3 illustrates the levels of parameters achieved at the maximum effort. The results obtained at the level of individual AT are shown in Table 4.

What this paper adds?

Physical activity undertaken by participants of the study largely limited the loss in respiratory efficiency as well as preserved their physical abilities at a high level. In the present study the spirometry results (VC, FVC, FEV₁₀/FVC, MVV), represented about 71% of predicted value for VC to 91.15% for MVV. Eight players displayed mild changes of restrictive type as a result of reducing functional lung volume. According to Baydur, quadriplegics have up to 50% lower VC and FCV than the predicted value. This is caused by the weakening of the respiratory and abdominal muscles. Baydur et al. in their study of tetra- and paraplegics observed that the loss of functional capacity of the respiratory system is dependent on the level of damage to the spinal cord [12]. Prigenth noticed that the results of spirometry studies of patients with spinal cord damage were better when the tests were carried out in recumbency. Similarly to Baydur, she explained this as a positive influence of the gravity force on the respiratory system [12, 13]. According to long standing observations of De Vivo, the



Figure 1. Exercise test

Group [n=14]	VC [1]	ERV [1]	VE [1/min]	Bf [breath /min]	VT [1]	FVC [l/min]	FEV _{1.0} /FVC [%]	MVV [l/min]
Mean	3.9	0.9	12.6	18.3	0.7	4.05	92.2	141.7
Standard deviation	0.71	0.33	6.34	4.72	0.2	0.69	7.1	24.59
% predicted	71.3	60.7	157	114	140	76.3	113.45	97.15

Table 2. Mean values of spirometric parameters

VC - vital capacity; ERV - expiratory reserve volume; VE - lung ventilation; Rf - breath frequency; VT - tidal volume; FVC - forced expiratory capacity; FEV_{10}/FVC - Tiffeneau rate; MVV - maximum voluntary ventilation

Table 3. Mean values of ergospirometric parameters (HR, workload, $VO_{2 peak}$, exercise time)

Group [n=14]	Exercise time [min]	HR max [beats/min]	Workload [W]	VO _{2 peak} [l/min]	VO _{2 peak} [mlO ₂ /kg/min]
Mean	11.8	124	42.5	1.31	17.8
Standard deviation	3.51	18.42	13.99	0.3	4.99

HR - heart rate; VO₂- oxygen uptake

Table 4. Mean values of ergospirometric parameters at AT

Group [n=14]	HR/AT beats/min	% VO _{2 peak}	Workload /AT [W]	VO ₂ /AT [l/min]	VO ₂ /AT [mlO ₂ /kg/min]
Mean	110.4	80.4	36	0.9	15.5
Standard deviation	19.63	5.67	10.62	0.26	4.17

HR - heart rate; VO₂- oxygen uptake; AT - anaerobic threshold

most frequent causes of death of people with cervical spinal cord damage include respiratory insufficiency and pneumonia [13, 14]. That is why all kinds of activities that help improve the weakened capacity of the respiratory muscles have a positive influence on the prognosis or survival of patients with quadriplegia.

Physical training undertaken by the examined wheelchair rugby players had a positive influence on respiratory efficiency. Some restricted changes in eight players and normal spirometry in six patients point to the positive influence of physical activity on the reduction of the

loss of respiratory function that occurred as a result of the subjects' disease and age. The study of Coutts from 1983 showed not only a correlation between the level of damage and the decrease in spirometric indices, but also between the level R = 0.6 and the decrease in maximal oxygen consumption (VO₂max). It means that in almost 60% of the examined players the level of aerobic capacity depended on the height of their spinal cord injury [15]. Literature abounds in studies that estimate the efficiency of non-training individuals, athletes as well as paraplegics and quadriplegics. The examinations are frequently carried out on a single subject. That is why the present study of 14 players with the same type of spinal damage and training

experience undoubtedly contributes to the state of knowledge in this field. The VO₂max obtained by the players in the presented study was on the average level of 17.8 ml/kg/min, with individual values ranging from 13.9 to 33.1 ml/kg/min. In two cases, the subjects attained the level of exercise oxygen consumption at 1.45 l/min; however, the high body mass index (25.5 kg/m² and 33.1 kg/m², respectively) differing significantly from the other players' caused low maximum oxygen consumption per kg of body weight. The high level of performance is demonstrated by the fact that ten of the

examined players obtained the load threshold at 80.4% of VO₂max, while their VO₂/PPA was an average of 0.99 ± 0.264 l/min (15.51 \pm 4.176 ml/kg/min). This value far exceeded the maximum oxygen consumption described in numerous publications. Dreisinger in his study of training quadriplegic observed significantly lower oxygen consumption at 0.78 l/min and Wicks at 13.8 ml/kg/min [16, 17]. Burkett in his research on training and non-training individuals suffering from spinal cord damage noted the maximum oxygen consumption for inactive quadriplegic ranging from 5.31 to 11.89 ml/kg/min for quadriplegics, from 13.07 ml/kg/min for women to 29.1 ml/kg/min for men. Among training individuals with diplegia the measured maximum oxygen consumption ranged from 26.18 to 30.42 ml/kg/min [18, 25]. The highest maximum oxygen uptake oxygen was recorded by Wells in training quadriplegics at 55 ml/kg/min [19].

According to Janssen, the level of aerobic fitness of individuals with spinal cord injury was good or very good [20]. It was so because of the performed physical activity that stimulated the maintenance of muscle mass and as well as development and maintenance of the function of the respiratory and circulatory system. Hopman et al. in their analysis of factors restricting the exercise ability, unambiguously pointed out that the loss of active muscle mass had the greatest effects on the reduction of exercise ability of the respiratory and circulatory system of individuals with spinal cord injury [21].

Conclusions

Physical activity undertaken at any age by both the able-bodied and the disabled has a positive influence on the maintenance or improvement of their physical abilities and thus on the improvement of their quality of life.

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