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Effectiveness of hospital-based low intensity and inspected aerobic training on functionality and cardiorespiratory fitness in unconditioned stroke patients

Importance of submaximal aerobic fitness markers

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Abstract

Introduction: The purpose of our study was to evaluate the effectiveness of low-to moderate intensity aerobic training on cardiorespiratory functions in chronic unconditioned stroke patients. The oxygen uptake efficiency slope (OUES) and the ventilatory threshold (VO_2-VT) could represent the aerobic capacity in submaximal test. Our study examined the application of the submaximal parameters for evaluating aerobic capacity of chronic stroke patients.

Materials and methods: In our assessor-blinded controlled pilot study 37 patients were randomized into 2 groups named: intervention group (IG, n: 21) and control group (CG, n:16), respectively. Cardiorespiratory functions were evaluated by ergospirometer before and after the 4-week (20 days) program. Both groups participated in daily occupational therapy (30 minutes) and conventional, customized physiotherapy CG (60 minutes), IG (30 minutes). Only IG performed aerobic training by bicycles (30 minutes) aiming to reach low-to moderate training intensity. Outcome measures included peak oxygen uptake (VO_2 peak), OUES, VO_2-VT, functional exercise capacity 6-Minute Walking Test (6MWT) and Functional Independence Measure.

Results: Thirty-five subjects completed the study. The VO_2 peak uptake was very low in both groups (IG: 11.9 mL/kg/min, CG: 12.45 mL/kg/min) and did not improve after the program, but submaximal parameters such as VO_2-VT ($P < .01$) and OUES ($P < .001$) have shown significant improvement, but only in IG regardless of insufficient impact on VO_2 peak. Each participant in both groups was unable to permanently reach the moderate intensity zone. Functional Independence Measure changed for the better in both groups, but 6MWT only in the IG.

Discussion and Conclusions: Four-week exercise training even at low intensity by lower limb cycle ergometer may provide benefit on aerobic and functional capacity without improvement of VO_2 peak on unconditioned chronic stroke patients.

Abbreviations: 6MWT = 6-minute walking test, ACSM = American College of Sports Medicine, CG = control group, BP = blood pressure, GTX = graded exercise test, HRmax, maximal heart rate, HRR = heart rate reserve, IG = intervention group, OUES = oxygen uptake efficiency slope, RER = respiratory exchange ratio, VCO2 = carbon dioxide production, VE = ventilation per minute, VO_2 = oxygen consumption, VO2 peak = peak oxygen uptake, VO_2-VT = ventilatory threshold.

1. Introduction

Stroke is one of the most common disabling conditions worldwide. A lot of physical disabilities caused by stroke may lead to a physically inactive lifestyle.[1] Most post-stroke patients also have other cardiovascular diseases and a very low exercise capacity as a consequence of long-term immobilization.[2] Physical fitness is very low after stroke, which may cause or aggravate some common post-stroke problems, including disability.[3] Activity limitation is manifested by reduced ability to perform daily tasks, and at 6 months after stroke, 40 % of stroke patients have difficulties with basic self-care (eating, dressing, showering).[4] The peak oxygen uptake ($VO_{2\ peak}$) which reflects of cardiovascular conditions and aerobic capacity is almost half (50%) of age- and sex-matched values in healthy inactive people.[5] The increased energy cost of movement after stroke also contributes to a sedentary lifestyle.[6]

Aerobic exercise training is foundational in improving cardiovascular fitness and other health outcomes in stroke

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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patients, by breaking a vicious cycle of physical inactivity and functional declining.[7] The American College of Sports Medicine (ACSM) suggested threshold intensity for training at 50% of HRR (heart rate reserve) or $VO_{2\ peak}$ for most adults and 40% of HRR or $VO_{2\ peak}$ for individuals with a low initial level of aerobic fitness. Aerobic Exercise Recommendation is more than 20 minutes that can be advised, depending on exercise frequency and intensity with a 3 to 5 minutes warm up and cool- down period.[8] There is a wide consensus that moderate to high intensity exercise aerobic training is more effective than low intensity training in the improvement cardiorespiratory fitness after stroke. Hollerand et al found in their examination that high intensity locomotion training might improve selected walking outcomes to a greater extent than low-intensity training in post-stroke individuals post-stroke.[8,9] In a recently published study the validation of submaximal test (OUES) for evaluating cardiorespiratory fitness in patients with stroke have raised the need to reconsider the effectiveness of low intensity training especially in case of unconditioned patient with very low baseline cardiorespiratory capacity. The intensity connects with baseline fitness level, neurologic involvement, cardiorespiratory state and previous comorbidity. Presently despite of the fact that low intensity (<40% HRR) training is not considered as aerobic exercise[10] and the 30 minutes of moderate intensity (40%-59% HRR) aerobic exercise on most days of the week was suggested during the rehabilitation period of stroke, the low intensity was the most commonly applied intensity by physiotherapist's.[8,11] Institutional, patient- and safety-related barriers underpinned the main reasons of the gap between recommendation and practice.[11] Stroke patients have difficulties to attain the preferable intensity training because of limb dysfunction, deconditioning, fatigue low motivation, depression and associated diseases. The study of Reynolds et al has demonstrated that low intensity standard stroke rehabilitation improved aerobic capacity.[12] The latest meta-analysis indicated that circle ergometer training at moderate-to-high intensity strongly improve the cardiorespiratory fitness and walking ability while others have found that routine rehabilitation therapy can also improve the aerobic capacity of stroke patients.[10,13] Despite of these controversial data, there is a wide consensus that low intensity training (<40% of HRR) cannot improve the aerobic capacity measured by $VO_{2\ peak}$, but the minimum volume and intensity of effective training for benefit in stroke survivors with very low exercise capacity remained unclear.[12]

Traditionally, the aerobic fitness, which may commonly limit the performance of daily activities, is determined by $VO_{2\ peak}$ measurement which demands the maximal effort and motivation of the patients. In case of stroke the maximal aerobic capacity is highly determined highly by motoric function rather than aerobic capacity. In addition, the high level of exertion can cause uncomfortable effect especially in stroke survivors. A very low percent of stroke patients can attain these challenges.[11] To avoid these limitations, several submaximal markers of aerobic fitness have been considered for evaluation.[14]

The oxygen uptake efficiency slope (OUES) and oxygen consumption (VO_2) at the ventilatory threshold (VO_2-VT) are 2 additional markers of aerobic capacity that can be obtained by ergospirometer examination.[11] The OUES has been evaluated during incremental exercise test and determined by the slope of the linear relationship between VO_2 and the logarithmic transformation of the ventilation values. The OUES measurement does not required maximal effort and is considered as a parameter that integrates cardiovascular, musculoskeletal and respiratory functions into a single index. Higher OUES values indicate more effective oxygen extraction and utilization.[10] The VO_2-VT represent the intensity limit of activity, while above that threshold the anaerobic metabolism begins. The VO_2-VT was determined by the V-slope graph where the VO_2-VT is the point of VO_2 intake at which the increase in carbon dioxide production ($\dot{V}CO_2$) is greater than the increase in VO_2.[16]

Emerging data have been arisen that the $\dot{V}O_2$-VT and the OUES may be more accurate measure of aerobic capacity than VO_2peak. These submaximal parameters are less distorted by the motoric function and motivation and do not demand maximal exertion causing exhaustion.[11] Nowadays the OUES has been applied in various diseases where the feasibility of maximal exercise test is highly limited including obesity, lung and heart diseases.[13] Novel data published recently have proven that the OUES is a valuable, valid and predictive index for evaluating cardiorespiratory fitness in stroke patient with low baseline exercise capacity or impaired limbs function.[13]

The primary aim of this study was to investigate the cardiorespiratory functions of chronic stroke patients by ergospirometer and to assess the effect of low- to- moderate intensity aerobic training integrating it into standard stroke rehabilitation care- on cardiorespiratory functions and submaximal cardiorespiratory parameters. A secondary aim was to evaluate the relationship between submaximal and other functional parameters. Our hypothesis was that these submaximal measures are to be more sensitive markers of preferable changes of cardiorespiratory functions than VO_2 peak changes particularly in the course of more sustainable low intensity training of stroke patients with very low fitness.

2. Methods

2.1. Design

An assessor-blinded, randomized-controlled clinical study was conducted Department of Physical Medicine and Rehabilitation, Faculty of Medicine, University of Debrecen, Hungary. Patients were enrolled between 2015 and 2017.The study was designed on the basis of CONSORT criteria.[17] The ethical permission was provided by the Hungarian Medical Research Council (24318/2016/EKU).

2.2. Participants

Eligible participants were those who had consented to take part in the study, had ischemic or hemorrhagic stroke more than 3 months ago, who were 18 to 75 years old, able to participate in the ergospirometer test without any cardiopulmonary signs or symptoms and able to walk (>50 m) with or without devices. Further inclusion criteria were the following: mild or moderate severity (according to National Institutes Health Stroke Scale), stabile health status with or without medications, understanding the commands (according to Mini Mental State Examination test's complex command task) and having no dementia, the sum of the points >23 point, whose ejection fraction is >40% (without beta-blockers) and blood pressure (BP) at rest is ≤140/90 mm Hg.

We excluded patients who had withdrawn their participations, who had unstable cardiopulmonary states (e.g., myocardial infarction within 3 months, arrhythmia etc), alcohol dependency, who had other chronic neurological disease (such as Parkinson's disease, multiple sclerosis etc) or musculoskeletal diseases, who had symptoms of peripheral arterial diseases, untreated depression, chronic pain (visual analogue scale more than 5) and untreated diabetes mellitus. During prescreening patients underwent a complete history revision and physical examination. The participants who were consented and fit to inclusion criteria, were randomized into 2 groups: intervention group (IG) and control group (CG). Randomization was done by a draw. Sixty–four patients were assessed for eligibility. Thirty-seven patients were screened and randomized into 2 groups, 2 persons dropped out, both from IG, due to a pulmonary embolism and withdrawal of consent. The main characteristics of the 2 groups were similar as we have published, though in the IG there was frequency of mental and cardiovascular comorbidities.[18]

The Flow Diagram. Illustrates the process of the study.

2.3. Interventions

All the participants' exercise tolerance was evaluated by a blinded assessor at the beginning and at the end of the therapy with an ergospirometer (Piston Ltd., Budapest, Hungary, SN: 101-E0D-2014-011). All the test was performed on a calibrated electromagnetically broken bicycle ergometer (Ergometer: Ergometer EBike Basic and BP, ergoline GmbH, Germany, SN: 2014004807). During the ergospirometer test, participants were asked to keep a candance of 55 to 65 revolutions per minute. The symptom and volitional exhaustion limited graded exercise test (GTX) comprised 2-minute warming period followed by a workload increase of 25 W per 2 minutes and 2-minute cool down). The termination criteria included: ST elevation (≥1.0 mm) in leads without preexisting Q waves because of prior MI (other than AVR, AVL, or V1) a drop in systolic BP of ≥10 mm Hg, despite the increase in workload, when accompanied by other evidence of ischemia, moderate-to-severe angina, central nervous system symptoms (ataxia, dizziness, syncope), signs of bad perfusion (cyanosis), and sustained ventricular tachycardia or other arrhyhtmias (atrioventricular block second or third degree). Tests were conducted in accordance with the ACSM guideline (2006). During testing, the measurements included resting heart rate and maximal heart rate (HRmax) by electrocardiogram, BP, VO_2, VCO_2, ventilation per minute (VE), load time, exercise time and respiratory exchange ratio (RER). VO_2peak was calculated as the highest 20 second average VO_2 rate during GTX.[10] VO_2, VCO_2, VE, and RER were continuously monitored during GTX tests using a breath-by-breath respiratory gas analysis. The criteria of a maximal effort included voluntary exhaustion and RER greater than 1.1. For evaluation of aerobic capacity VO_2-VT (V-slope method) and OUES values were determined as submaximal measures. VO_2-VT is identified when VO_2 at which the change in slope of the relationship of VO_2 to VCO_2 occurs. The software automatically established the regression lines and their crossing points.[16] OUES using the equation: VO_2 (mL/min) = OUES*log10 VE (L/min) + intercept; where OUES is the slope of the regression line of VO_2 versus log transformed expiratory flow volume. Greater OUES values indicate higher ventilator efficiency. To evaluate the accuracy of the OUES in submaximal exercise intensity and to assign the predictive validity of the submaximal OUES, we calculated the OUES at 50%, 75%, and 100% of maximal exercise duration (OUES50, OUES75, OUES100). The HRmax during the GTX was the average HR during the last 30 seconds of exercise. Target training pulse rate (HR target) was calculated at the first assessment according to Karvonen equation (HR target=/ (HR max–HR rest) X 0.4-0.6)/+HR rest.

The therapy was performed on 20 consecutive weekdays (5-days/week therapy and 2 days/week rest). Both groups participated in conventional, customized physiotherapy, dealing with upper and lower limb (IG: 30 minutes, CG: 60 minutes) and during occupational therapy for upper limb development goal-directed, high intensity repetitive training was applied for the affected upper limb (both groups: 30 minutes). Both groups did special tasks (3-5 sessions) for 30 minutes, the repeating number was 70-100.[19] The task prescription considered individual goals by allowing each participant to choose 3 to 5 activities that they would like to accomplish. IG performed anaerobic training with stationary bicycles (30 minutes) (Christopeit, Top-Sports Gilles, Germany, SN: DE18272186) aiming to reach the personal target pulse rate. The training commenced at 5 to 10 minutes and progressed each session (if tolerated) until 30 minutes and it was symptom-limited, had a warm-up (5 minutes), a therapy (20 minutes), and a cool- down (5 minutes) phase. Physiotherapy of CG also included 5-minutes low intensity stationary bike exercise to reduce the impact of a lack of practice during the ergospirometer test. HR and Borg Rating of Perceived Exertion were monitored in both groups every 5 minutes to ensure participants maintained or not their target training pulse. Short rest breaks were allowed as required in both groups.

2.4. Outcome measurements

Evaluations were made at baseline and 4 weeks later. HR was checked during cycling and conventional therapy session in every 5 minutes. (Handheld Pulse Oximeter, Guangdong Biolight Medtech Co., Ltd., China, SN: M01EO18751). Patients had to reach at least 40% of their own HRR, which was measured prior to the session. BP was monitored before and after the session (Rextra, F.Bosch Practicus, Germany,SN: K140623).

For evaluation of maximal exercise capacity HRmax, metabolic equivalent (MET), VO_2-peak and load time, for evaluation of aerobic capacity VO_2-VT and OUES as submaximal tests, were measured.

The 6-minute walking test (6MWT) measured the cardiovascular endurance and the Functional Independence Measure assessed the global functional capacity. Borg Rating (6–20 scale) of Rating of Perceived Exertion was used for evaluation of exercise intensity of the therapies.[20] The scale allows individuals to subjectively rate their level of exertion during exercise or exercise testing (ACSM, 2010). It ranges from 6 to 20. 6 means no exertion at all and 20 means maximal exertion.

2.5. Statistical analysis

All statistical analyses were performed by using the SAS for Windows (Ver. 8.2, SAS Institute Inc., Cary, NC). Data are expressed as median (interquartile range/IQR/). $P < .05$ was considered statistically significant. Non-parametric tests were used because results were not normally distributed. Wilcoxon signed ranks test was used for inside group and Mann–Whitney *U* test was used aiming between group analyses. To test the correlation between submaximal parameters OUES and VO_2-VT and VO_2 peak the Pearson correlation analysis was used.

3. Results

The median of basal VO_2 peak was extremely low in both groups before the study and did not improve after rehabilitation program. All the participants reported a Borg rating of PRE >17 and 98% of them reached RER > 1 in the course of ergospirometer which indicated that almost all the participants terminated their test due to fatigue or subjective feeling of exhaustion. Neither the cycle ergometer training patients, nor the control patients attained their own target pulse (≥40% of HRR) permanently. The limit for increasing the load was fatigue. All the patients of both groups attained only low intensity training within 30% to 39% of HRR zone, however there was a significant difference between the average of training pulse (IG: 37.23% ± 3.4% of HRR and CG: 32.23% ± 2.87% of HRR min, $P < .05$). Regarding the baseline data the intergroup analysis showed non-significant difference between the 2 groups in either of the cardiorespiratory or functional tests. After the rehabilitation program there were no significant changes in groups regarding VO_2 peak, MET, HRmax, RER and load time. However, in the submaximal tests such as aerobic threshold defined by VO_2-VT ($P < .01$), OUES50 ($P < .01$), OUES75 ($P < .01$), OUES100 ($P < .001$) significant improvements were found, but only in IG regardless of insufficient training effect on VO_2 peak. In the global test of Functional Independence

Measure a significant improvement was found in both groups, whereas 6MWT improved only the in IG ($P < .01$). There were significant between-group differences only in submaximal tests (OUES 50-100, VO_2–VT, and 6MWT). No adverse events were reported during testing or training session in either group (Table 1).

3.1. Correlation analysis

There was a significant correlation between VO_2 peak and VO_2-VT, OUES50, OUES75 and OUES100 ($R = 0.64$, $P = .001$ $R = 0.47$, $P < .005$, $R = 0.55$ $P < .001$, and $R = 0.59$, $P < .001$, respectively). The relationships between submaximal indicates were also significant: OUES50 and OUES100 ($R = 0.777$, $P < .001$), OUES75 and OUES100 ($R = 0.77$, $P < .001$) OUES50 and OUES75 ($R = 0.60$, $P < .001$).

4. Discussion

Incorporation of the exercise in the stroke rehabilitation program is essential in the risk prevention of future cardiovascular events including recurrent stroke *and long-term disability. Data have shown that almost quarter of patients have an adverse event (died or disability) 1 year after stroke*.[21,22] Corroborating previous data, our study demonstrated that inactive subacute and chronic stroke patients with preserved walking ability had extremely low VO_2 peak and they were unable to attain sufficient, moderate intensity training (≥40% HRR) to improve their cardiorespiratory capacity.[21,23] The poor post-stroke exercise capacity, regardless of motoric impairment is considered to be one of the main limitation factors of independent activity of daily living.[24] Additionally the gait training and motor learning after stroke are associated with high energy and oxygen demand thus stroke patients with poor aerobic capacity could not participate in these sessions. Despite of data of the latest meta-analysis suggesting the beneficial effect of aerobic training on cardiorespiratory functions and walking ability, the most rehabilitation program does not comprise effective exercise training.[8]

The main challenge in the exercise training prescription of stroke patient is the intensity considering the potential cognitive and motor impairment or other confounding factors such as associated musculoskeletal and cardiopulmonary diseases.

While many studies have found that moderate (40%-59% HRR) and high intensity (60%-84% HRR) aerobic exercise significantly improve exercise capacity, the low intensity (<40% HRR) is prescribed for most people with stroke.[12] The moderate- intensity fitness training safe but achievement of target duration and intensity was challenging for chronic stroke patients.[12]

Despite of the fact that the previous studies and the current recommendation have suggested that the low intensity training during traditional stroke rehabilitation is insufficient, the literature arises the beneficial effect on gait function, balance, cardiovascular risk factors and especially on cardiorespiratory fitness functions measured by submaximal test.[21,26]

This study has demonstrated that implementation of low intensity aerobic training added to usual care of hospital - based inpatient stroke rehabilitation setting is to be more effective than usual care alone on improvement of cardiorespiratory fitness, aerobic capacity and its submaximal markers (VO_2-VT, OUES).

Table 1

Changes of cardiorespiratory capacity and functional ability in Intervention and Control group.

	Intervention group N = 19			Control group n = 16			
Median (Q1-Q3)	Admission	Discharge	Inside group significance (*P*)*	Admission	Discharge	Inside group significance (*P*)*	Between group difference (*P**)
VO_2 peak mL/kg·min	11.9 (9.85-16.70)	11.9 (11.15-5.05)	.809	12.45 (9.83-14.85)	12.45 (9.83-14.85)	.569	.78
MET	3.40 (2.80-4.80)	3.40 (3.20-4.30)	.762	3.55 (2.78-4.23)	3.65 (2.68-4.10)	.516	.82
Load time min	7.00 (5.15-8.80)	7.30 (6.15-8.80)	.082	7.64 (6.30-8.48)	8.00 (5.80-10.08)	.364	.69
HRmax (bpm)	125 (100-141)	127 (102-144)	.56	130 (117-135)	132.5 (114.5-138)	.82	.74
% of predictived HRmax	76.68 (60.81-84.90)	75.86 (60.81-84.90)	.61	83.10 (72.19-85.73)	79.36 (74.11-89.03)	.12	.88
VO_2-VT mL/kg/min	9.64 (7.71-1.05)	11.42 (9.08-12.95)	<.01*	9.28 (7.74-10.35)	9.49 (7.90-11.18)	.46	<.05
$OUES_{50}$	364 (72-953)	427.5 (102-1303)	<.01*	350 (127-958)	385 (7-967)	.7	<.05
OUES75	540 (85-1157)	734 (186-1830)	<.01*	448 (201-1147)	470 (164-1100)	.18	<.05
OUES100	848.5 (153-1568)	1056 (294-1883)	<.0001*	883 (365-1820)	943 (320-1596)	.68	<.05
RER	1.05 (1.02-1.08)	1.03 (0.99-1.06)	.395	1.01 (1-1.05)	1.02 (0.95-1.05)	.292	0.72
Exercise duration(min)	7 (5-9.5)	7.5 (5-9.5)	.41	7.75 (6.5-8.5)	8 (5.5-10.5)	.63	.84
6 MWT (m)	235,8 (115-340)	312,6 (142-390)	<.01*	210,45 (101-320)	232 (112-330)	.21	<.05
FIM	115.00 (108-120)	117.00 (114-122)	<.01*	117.5 (113-121)	120.50 (118-123)	<.01*	

n = number, p = level of significance, Q1 = first quartile, Q3 = third quartile, VO_2 peak = peak oxygen consumption, MET = metabolic equivalent, HR = heart rate, VO_2 = VTventilatory threshold, OUES = oxygen uptake efficiency slope, OUES50, OUES75, OUES100 (OUES at 50%, 75%, and 100% of maximal exercise duration), RER = respiratory exchange ratio, FIM = Functional Independence Measure, 6MWT = 6 minutes walking test.

*Significance level was $P < .05$.

The basic characteristics of the 2 groups were quite similar. During the rehabilitation program neither IG nor the CG patients could attain the moderate training pulse zone, consequently the maximal tests of VO_2 peak HRmax, load time and MET did not improve. Apparently, the VO_2 peak is the most common measure to evaluate the aerobic capacity after stroke but it is highly determined by the motor dysfunction (e.g., paresis), cognitive and mental status (motivation) and this can occur well before VO_2 peak is reached.[27]

The OUES and the VO_2-VT are 2 additional measures of aerobic capacity that can be obtained from ergospirometer.[27] These markers are believed to be more specific and sensitive markers of aerobic capacity, since the motor function does not affect it and is weakly related to peak exercise intensity and VO_2 peak.[28] The results showed the same outcomes with Sheng Chien at al., that truthfulness of OUES50, OUES75, and OUES100 (the correlation between log VE and VO_2) was standout. These outcomes indicate that the OUES from submaximal exercise duration was stable. Furthermore, both OUES50 and OUES75 were highly correlated with the OUES100.[13]

Interestingly in our study a significant improvement in VO_2-VT and OUES measures were found only in the IG group despite similarly low training intensity to CG. However, in the IG the average achieved training pulse was significantly higher than in CG but under the 40% HRR level. This difference may explain the more effective improvement in aerobic capacity in the IG. Almost all the participant achieved RER = 1 and Borg rate of PRE > 17 demonstrating their maximum effort before termination of exercise test.

Our data suggest that, even at low intensity, the utilization of exercise training especially by lower limb cycle ergometer may be beneficial for aerobic capacity of extremely unconditioned post-stroke patients without improvement of VO_2 peak. Concurrently with other previous data our study underlines that extremely low VO_2 peak is only partially caused by deconditioning, the motor dysfunction can also be found as underlying condition.[27] Avoiding this bias using submaximal measures it seems the low intensity exercise also has a significant training effect improving aerobic performance of post-stroke patients.[8] Previous studies indicated the low intensity aerobic training can be beneficial for improving gait speed and gait economy, gait strength, and walking endurance..[29,30] Although this effect is certainly not as effective as moderate-to-high- intensity, its importance is not irrelevant to the point of view of prevention of further deconditioning of subacute and chronic stroke patients. A potential mechanism of this effect origins from the fact that the cycle ergometer training strengthens the muscles of lower limb causing increased blood flow and vascularization, which leads better oxygen availability, extraction capacity, utilization and acidosis control in the affected muscles. The better muscle power decreases the force at the same exertion level and highly determines the OUES.[14] On the other hand the metabolism of the related muscles under using cycle ergometer partly relies on anaerobic glycolysis increasing peripheral local lactate response and consequently improved lactate clearance. This training adaptation can explain the improvement of VO_2-VT.[31]

5. Conclusions

Our randomized controlled study indicates that the extremely low VO_2 peak and exercise capacity of the subacute and chronic stroke patients are just partly related to deconditioning, while the stroke-associated motor dysfunction can be another main contributor. Submaximal markers of aerobic capacity (OUES and VO_2-VT) appeared to be a better and sensitive marker of aerobic capacity than VO_2 peak eliminating these limitations related to several barriers such as motor and mental disorders. The low intensity aerobic training especially by cycle ergometer as the most common prescribed and feasible exercise intensity form after stroke has a beneficial effect on improving aerobic capacity beside the advantageous on walking ability. Our data highly support the integration of aerobic training even at low intensity into stroke rehabilitation process.

6. Limitation

Our 4-week examination period might, be short evaluate all parameters extensively. It is worth to extend the period for a longer time, as patients need a longer time to adapt to the enhanced load and reach more improvements in the parameters which measure cardiorespiratory fitness.

References

[1] Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stoke: the role of balance, gait, and cardiovascular fitness. Arch Phys Med Rehabil. 2005;86:1552–6.

[2] Hafer-Maco CE, Ryan AS, Ivey FM, et al. Sceletal muscle changes after hemiparetic stroke and potential beneficial effect of exercise interventention strategies. J Rehabil Res Dev. 2008;45:261–72.

[3] Brazelli M, Saunders DH, Greig CA, et al. Physical fitness training for patents with stroke, cochrane corner. Stroke. 2012;43:e39–40.

[4] Mayo NE WS, Cote R, Durcan L, et al. Activity, participation, and quality of life 6 month poststroke. Arc Phys Med Rehabil. 2002;83:1035–42.

[5] MacKay-Lyons MJ, Makride L. Longitudinal changes in exercise capacity after stroke. Arch Phys Med Rehabil. 2004;85:1608–12.

[6] Billinger SA, Arena R, Berhardt J, et al. Physical activity and exercise recommendations for stroke survivors: a statement for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2014;45:2532–53.

[7] Pang MYC, Charlesworth SA, Lau RWK, et al. Using Aerobic Exercise to improve health outcomes and quality of life in stroke: evidence – based exercise prescription recommendation. Cerebrovascular Dis. 2013;35:7–22.

[8] MacKay-Lyons M, Billinger SA, Eng JJ, et al. Aerobic exercise recommendations to optomize best practices in care after stroke: AEROBICS 2019 update. Phys Ther. 2020;100:149–56.

[9] Holleran CL, Rodriguez KS, Echauz A, et al. Potential contributions of training intensity on locomotor performance in individuals with chronic stroke. J Phys Ther. 2015;39:95–102.

[10] Veldema J, Jansen P. Ergometer training in stroke rehabilitation: systematic review and meta-analysis. Arch Phys Med Rehabil. 2020;101:674–89.

[11] Boyne P, Billinger S, MacKay-Lyons M, et al. Aerobic exercise prescription in stroke rehabilitation: a web-based survey of US physical therapists. J Neurol Phys Ther. 2017;41:119–28.

[12] Reynolds H, Steinfort S, Tillard J, et al. Feasibility and adherence to moderate intensity cardiovascular fitness training following stoke: a pilot randomized controlled trial. BMC Neurol. 2021;21:132.

[13] Sheng-Chien H, Tieh-Cheng, Chih-Chih H, et al. The validation of oxygen uptake efficiency slope in patients with stroke. Medicine. 2021;100:e27384.

[14] Masahito M, Junichi K, Masao H, et al. Physical fitness and exercise endurance measured by oxygen uptake kinetics in stroke patients. J Phys Ther Sci. 2002;14:73–6.

[15] Pasqua L A, Damasceno M D, Lima-Silva A E. Maximal and submaximal oxygen uptake efficiency slope: influence of cardiorespiratory variables and maximal dynamic strength. Pulm Crit Care Med. 2017;2:1–5.

[16] Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol. 1986;60:2020–7.

[17] Levack WMM, Patrick Engkasan J, Heinemann AW. A review of CONSORT reporting Guidelines about comparison groups with a focused discussed on implication for rehabilitation trials. Am J Phys Med. 2020;99:191–7.

[18] Debreceni-Nagy A, Horváth J, Bajuszné Kovács N, et al. The effect of low-intensity aerobic training on cognitive functions of severely deconditioned subacute and chronic stroke patients: a randomized, controlled pilot study. Int J Rehabil Res. 2019;42:275–9.

[19] Linder SM, Anson B, Rosenfeldt MR, et al. Forced aerobic exercise enhances motor recovery after stroke: a case report. Am J Occup Ther. 2015;69.

[20] Borg, G. Borg's Perceived Exertion and Pain Scales. Champaign, IL: Human Kinetics. 1998, pp. 1–101.

[21] Billinger SA, Boyne P, Coughenour E, et al. Does aerobic exercise and the FITT Principl fit into stroke recovery? Curr Neurol Neurosci Rep. 2015;15:519.

[22] Wen-Jun T, Bao-Hua C, Lin M, et al. Case- fatality and reccurence rates after first-ever stroke: a study from bigdata observatory platform for stroke of China. Brain Res Bull. 2021;175:130–5.

[23] Billinger SA, Coughenour E, Mackay-Lyons MJ, et al. Reduced cardiorespiratory fitness after stroke: biological consequences and exercise-induced adaptations. Stroke Res Treat. 2012;2012:959120.

[24] Tang A, Sibley KM, Thomas SG, et al. Effects of an aerobic exercise program on aerobic capacity, spatiotemporal gait parameters, and functional capacity in subacute stroke. Neurorehabil Neural Repair. 2009;23:398–406.

[25] Pang MY, Eng JJ, Dawson AS, et al. The use of aerobic exercise training in improving aerobic capacity in individuals with stroke: a meta-analysis. Clin Rehabil. 2006;20:97–111.

[26] Katz-Leurer M, Sender I, Keren O, et al. The influence of early cycling training on balance in stroke patients at the subacute stage. Results of a preliminary trial. Clin Rehabil. 2006;20:398–405.

[27] Boyne P, Reisman D, Brian M, et al. Ventilatory threshold may be a more specific measure of aerobic capacity than peak oxygen consumption rate in persons with stroke. Top Stroke Rehabil. 2017;24:149–57.

[28] Balady GJ, Arena R, Sietsema K, et al. Clinician's Guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. Circulation. 2010;122:191–225.

[29] Macko RF, Ivey FM, Forrester LW, et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. Stroke. 2005;36:2206–11.

[30] Jin H, Jiang Y, Wei Q, et al. Effects of aerobic cycling training on cardiovascular fitness and heart rate recovery in patients with chronic stroke. NeuroRehabilitation. 2013;32:327–35.

[31] Marzolini S, Brooks D, Oh P, et al. Aerobic with resistance training or aerobic training alone poststroke: a secondary analysis from a randomized clinical trial. Neurorehabil Neural Repair. 2018;32:209–22.