Review
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Ergospirometric assessment: Relevance for rehabilitation of stroke subjects.

Avaliação ergoespirométrica: relevância na reabilitação de indivíduos pós acidente vascular encefálico.

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Abstract

Introduction: Cardiorespiratory fitness is markedly reduced in stroke subjects, resulting in patterns of inactivity and sedentary lifestyles. In this sense, tests of aerobic exercises are critical for the prescription of this type of training. **Aims:** To review the available data regarding the cardiorespiratory, metabolic parameters, and protocols used to assess cardiorespiratory fitness in stroke subjects, and to discuss their relevance for stroke rehabilitation. **Method**: A literature review was carried out in MEDLINE, CINAHL, EMBASE, and PEDro databases. The articles identified by the initial search strategy were evaluated, according to the following criteria: (1) the target population included stroke subjects, (2) employed a spirometric instrumentation, (3) reported results from randomized clinical trials, experimental, or quasi- experimental designs, and (4) included in the analyses any cardiorespiratory or metabolic parameters to assess cardiorespiratory fitness. **Results:** The 15 identified studies included a total sample of 665 stroke subjects. The experimental groups received training on cycle ergometers, treadmills, mobility, water, and unilateral lower limb exercises with isokinetic dynamometer. Most studies assessed oxygen consumption, two analyzed anaerobic threshold, and one examined heart rate and respiratory exchange ratios. **Conclusions:** Although differences between the studies were found regarding the investigated outcomes, the assessment and training protocols, this review found evidence that cardiorespiratory parameters, mainly oxygen consumption, were sensitive to training.

Key-Words: Stroke, hemiparesis, physiotherapy, physical fitness.

Resumo

Introdução: A aptidão cardiorrespiratória é marcadamente reduzida em indivíduos pós Acidente Vascular Encefálico (AVE), acarretando um padrão de vida sedentário e inatividade. Nesse sentido, testes de exercício aeróbico são críticos para a prescrição deste tipo de treinamento. **Objetivo:** Revisar a literatura disponível acerca dos parâmetros cardiorrespiratórios, metabólicos e protocolos utilizados para avaliação da aptidão cardiorrespiratória em indivíduos hemiparéticos pós AVE, além de discutir a relevância dos mesmos. **Método:** Foi conduzida uma revisão da literatura nas bases de dados *MEDLINE, CINAHL*, *EMBASE* e *PEDro.* Os artigos identificados pela estratégia de busca inicial foram avaliados conforme os seguintes critérios de inclusão: (1) possuíam população-alvo constituída por hemiparéticos pós-AVE; (2) utilizaram ergoespirometria como instrumentação; (3) relatavam ensaios clínicos aleatorizados, estudos experimentais ou quase-experimentais e (4) realizaram a análise de algum parâmetro cardiorrespiratório ou metabólico para avaliação da aptidão cardiorrespiratória. **Resultados**: Foram encontrados quinze estudos, com amostra total de 665 hemiparéticos. Os grupos experimentais foram constituídos de exercícios em cicloergômetros, esteira, exercício unilateral de membro inferior no dinamômetro isocinético, exercícios de mobilidade e condicionamento ou exercícios aquáticos de resistência. A maioria dos estudos utilizou a variável consumo de oxigênio; dois analisaram o limiar anaeróbio e somente um analisou a freqüência cardíaca e a razão da troca respiratória. **Conclusão:** Apesar de os estudos terem apresentado divergências dentre as varáveis analisadas e protocolos de avaliação e treinamento, observaram-se evidências que variáveis cardiorrespiratórias, principalmente o consumo de oxigênio, são sensíveis ao treinamento.

Palavras-chave: Acidente Vascular Cerebral, hemiparesia, fisioterapia, aptidão física.

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INTRODUCTION

The relationships between exercise versus health status have always been a concern, since the reports of Hippocrates and Galen, who studied these relationships by observation and experimental procedures. Over the years, the technological advances have enabled on-line accurate measurements of metabolic and cardiorespiratory parameters, by means of closed-loop circuits and more recently with gas analyzers, which provide fast automatic data records by means of open systems.(1) Ergospirometry evaluates not only the functional reserve capacity of the cardiopulmonary system, but also provides data regarding functioning of the various systems involved in physical exercise responses. Thus, ergospirometry is a non-invasive resource of great importance for the evaluation of the cardiac function of both athletes and individuals with disease.(2.3)

Cardiorespiratory fitness is affected by several health conditions, such as those which predispose individuals to changes in the cardiovascular and respiratory systems and affect the musculoskeletal system. Within this context, individuals with mobility limitations are likely to become sedentary and/or inactive. This, in turn, leads to changes in musculoskeletal, metabolic, cardiovascular, and respiratory systems. Stroke subjects fit into this vicious cycle, which hinders their reintegration into daily life activities,(4), since stroke is responsible for the majority of chronic disabilities worldwide.(5)

Although previous studies reported that stroke subjects engage less in physical activitiy, compared with healthy adults,(6) recently it was pointed out that this reduction was not due primarily to the time taken to perform the activity, but due to the decreased frequency during the time taken for its realization. In other words, stroke subjects perform physical activities slower,(7) which could be caused by changes of the metabolic and cardiorespiratory systems. In addition, the practice of physical activity is of utmost importance for these subjects, since it was reported that even at moderate intensities, regular practice of physical activity has neuroprotective effects, which reduce the incidence and recurrence of stroke.(8,9)

Thus, considering the need for comprehensive assessment of individuals after stroke and the importance of understanding the parameters related to cardiorespiratory fitness, this study aimed to review the available literature regarding the cardiorespiratory and metabolic parameters, the protocols employed for the assessment of cardiorespiratory fitness with stroke subjects, as well as discuss their clinical relevance.

METHODS

A search was carried-out on the Pubmed, LILACS, CINAHL, EMBASE, and PEDro databases in October 2013 and included studies published since 1991, without language restrictions. This review included only fully published papers, which were extracted based upon the following descriptors: "stroke", "hemiparesis" and "hemiplegia" combined with "cardiorespiratory" and "cardiovascular fitness"

Studies were included if: (1) The target population consisted of stroke subjects; (2) employed spirometry, as their instrumentation; (3) were randomized clinical trials, experimental or quasi-experimental designs, and (4) included the analyses of any cardiorespiratory or metabolic parameters for the assessment of cardiorespiratory fitness. In addition, a manual search was carried out on the retrieved papers and other relevant studies were also included to support the discussion.

RESULTS

Of the 362 retrieved articles, 34 were selected after reading the titles and abstracts. Out of the 34, 19 were excluded after reading the full text, because they did not fit into the established criteria. Therefore, 15 studies were finally included in the analyses.

The analyses involved a total sample of 663 stroke subjects and nine studies included individuals in the acute and sub-acute phases (<6 months post-stroke). The other six studies included subjects during the chronic stages (>6 months post-stroke). The experimental groups were submitted to training on cycle ergometers, treadmills, as well as mobility, water resistance, and unilateral lower limb exercises on the isokinetic dynamometer, mobility and conditioning exercises or water exercises for resistance. Thirteen studies had control groups (*n*=288), which received not-specified "conventional therapy", stretching exercises, exercises for the upper limbs in the seated position, passive exercises, and joint mobilization. In one study, the control group did not receive any intervention. The average time of the intervention was 10.7±7 months(3-24) with daily session durations ranging from 30 minutes to three hours, and with a weekly frequency ranging from three to five times per week.

The main characteristics of the included studies are described in Table 1, where the results of the interventions are shown with "+", when they favored experimental groups "-", when they favored the control groups; and "0", when no significant differences between the groups were found or when no other differences were found between the experimental groups regarding the metabolic and cardiorespiratory parameters.

DISCUSSION

The studies analyzed in this review(10-25) showed, in general, improvements of the cardiorespiratory parameters associated with various interventions. These findings are extremely important, since it is reported that

Table 1. Main characteristics of the included studies (n=15)

Authors	Sample	Time post-stroke	Experimental group	Control group	Analyzed parameters	Results*
Potempa *et al.*[25]	*n*=42	216±40 days	Aerobic cycle ergometer training (*n*=19)	Passive exercises and joint mobilization (*n*=23)	Peak VO_2 Peak workload Minute ventilation	+ + +
da Cunha *et al.*[21]	*n*=15	19±3 days	Regular rehabilitation + treadmill training (*n*=6) Cycle ergometer training (*n*=6)	Conventional rehabilitation (*n*=7)	Peak VO_2	0
Katz-Leurer *et al.*[19]	*n*=92	Not reported	Cycle ergometer aerobic training (*n*=46)	Not reported (*n*=46)	Maximum reached load (Watts) at 60% of the maximal heart rate	+
Duncan *et al.*[12]	*n*=92	75±27 days	Supervised home-based cycle ergometer aerobic training (*n*=44)	Conventional physiotherapy* (*n*=48)	Peak VO_2	+
Chu *et al.*[18]	*n*=12	3.5±2 days	Water resistance exercises (*n*=6)	Upper limb exercises (*n*=6)	Peak VO_2	+
Okada[17]	*n*=15	Not reported	Conventional physiotherapy* (*n*=15)	None	Anaerobic threshold	+
Macko *et al.*[20]	*n*=45	37±40 months	Aerobic treadmill training	Conventional physiotherapy**	Peak VO_2	+
Pang *et al.*[16]	*n*=63	5±4 years	Mobility exercises and aerobic training (*n*=32)	Upper limb exercises (*n*=31)	Peak VO_2	+
Pang *et al.*[15]	*n*=63	5±4 years	Lower limb exercises (*n*=32)	Upper limb exercises (*n*=31)	Peak VO_2	+
Lee *et al.*[10]	*n*=52	57±4 months	I: Cycle ergometer aerobic training + placebo resistance training (*n*=13) II: Placebo cycle ergometer aerobic training placebo + endurance training (*n*=14) III: Cycle ergometer aerobic training + endurance training (*n*=4)	IV: Placebo cycle ergometer aerobic training + placebo resistance training (*n*=14)	Peak VO_2 Peak heart rate Heart rate/speed VO_2/speed	+ + + + for groups I and III
Rimmer *et al.*[22]	*n*=55	<6 months	Cycle ergometer aerobic training: I: Mmoderate intensity and low duration (*n*=18) II: Low intensity and high duration) (*n*=18)	III: Conventional therapeutic exercises** (*n*= 18)	Peak VO_2 Submaximal VO_2	0 0
Quaney *et al.*[11]	*n*=38	5±3 years	Aerobic treadmill training (*n*=19)	Stretching exercises (*n*=19)	Peak VO_2	+
Tang *et al.*[24]	*n*=41	17±2 days	Conventional physiotherapy* + cycle ergometer aerobic training (*n*=23)	Conventional physiotherapy** (*n*=18)	Peak VO_2 Maximum load Anaerobic threshold Peak heart rate	+ + 0 +
Letombe *et al.*[13]	*n*=18	20±2 days	Conventional physiotherapy* + cycle ergometer aerobic training (*n*=9)	Conventional physiotherapy** (*n*=9)	Peak VO_2	+
Billinger *et al.*[14]	*n*=20	69±82 months	Unilateral isokinetic exercises (*n*=20)	None	Peak VO_2 RER Peak heart rate	+ 0 -

* (+)=favored the experimental groups (-)= favored the control group; (0)= no significant differences between the groups; ** not-specified ; VO_2=oxygen production; RER= respiratory exchange ratio;.

heart diseases are the main cause of death in stroke survivors.[26] Additionally, after discharge from rehabilitation, 60-70% of individuals regain the ability to walk independently; however, only 7% recover the capacity for community ambulation[27]. For this activity, one of the requirements is first of all, cardiorespiratory fitness, which is reduced in this population. The literature demonstrated that stroke subjects show, during maximal exercise the peak oxygen consumption (VO_2) values lower than those of healthy individuals, matched by age and gender. In the same way, the energy costs and cardiovascular demands during submaximal exercise are significantly higher, when compared to healthy individuals.[25] Thus, reduced cardiorespiratory fitness could be a limiting factor for the transfer of acquired new skills during rehabilitation to real life situations.[28]

CARDIORESPIRATORY PARAMETERS

Oxygen Consumption

Oxygen consumption (VO_2) is defined as the volume of oxygen (O_2) extracted from the inspired air by pulmonary ventilation in a given period of time and it is calculated as the difference between the volume of O_2, which is inhaled and exhaled. The VO_2 is dependent upon the exercise intensity and is the parameter that best measures cardiorespiratory fitness and exercise capacity. Several factors could influence the VO_2, including the type of exercise, gender, age, size and body composition, and levels of regular physical activity.[3,29]

Several studies examined *VO_2* [10-14,16,18,20-22,24,25] and even using different training protocols, only da Cunha *et al*.[21] and Rimmer *et al.*[22] did not observe significant increases in this parameter after interventions. Studies usually assessed the peak VO_2, because maximal tests for these subjects are not always considered valid, since their ability to perform this test is compromised by the musculoskeletal limitations imposed by the stroke.[30] Additionally, Rimmer et al.[22] employed the submaximal VO_2, which is an indicator of physiological reserves and gross motor efficiency.[31] The results of the studies showed that even with short periods of intervention and sessions, the ability to exercise can be increased, regardless of the post-injury phase. In this sense, interventions focused on cardiorespiratory fitness should be implemented as part of the rehabilitation program from the early stages post-stroke, preventing the decline of cardiorespiratory fitness.

There is a close relationship between measures of VO_2 and heart rate during exercise, since the cardiac responses should be proportional to the increases in oxygen consumption, so that the system can receive the necessary levels to meet the required demands. In this sense, a linear relationship between VO_2 and heart rate during aerobic exercise appears to exists.[32]

Heart rate

Heart rate (HR) is the chronotropic response to exercise and is of great value due to its relationship with VO_2, as previously discussed.[3] Only Lee *et al.*[10] assessed HR as an outcome and observed its increases associated with various exercise speeds.

Anaerobic Threshold

Anaerobic threshold (AT) indicates the speed that sustained rate of lactate accumulation (LA) occurs in the blood stream and can be either directly obtained or non-invasively estimated. The LA is a marker of cardiorespiratory fitness and limiting factor of exercise intensity, being sensitive to training in both athletes and individuals with disease. This parameter can have a potential clinical value suggesting peripheral cardiovascular limitations and clinically useful prognostic indicators.[3,29] For non-invasive estimations, the LA can be determined by methods, such as gas exchanges (V-slope) or graphic visual methods.[3]

The LA was examined in only two studies. Okada[17] and Tang *et al*.[24] found no differences in LA after treatment with conventional therapy, and conventional physiotherapy associated with aerobic training on a cycle ergometer, respectively. These findings could be explained by the fact that the interventions were performed over short periods (average of 47 days and 4 weeks, respectively), which could not be sufficient to lead to significant changes in this parameter. Furthermore, the protocol which was used for the assessment of LA, was not reported.

Respiratory Exchange Ratio

The respiratory exchange ratio (RER) is defined as the ratio between the release of carbon dioxide (CO_2) and pulmonary oxygen uptake, measured from the exhaled air (VCO_2/VO_2). This parameter reflects the increment of load to the fitness levels of the individual and the use of carbohydrates in the mixture of metabolized substrates.[3,29]

Billinger *et al.*[14] were the only ones who assessed RER and reported no significant changes after unilateral training with an isokinetic dynamometer three times a week over four weeks. These findings could be explained by various factors, such as the participants' musculoskeletal impairment levels, insufficient load increases, or the exercise levels may have been insufficient to promote significant improvements in this parameter. Moreover, the employed protocol might not have increased venous return, which would not provide increases in cardiac work, and therefore, did not result in significant increases of VO_2.

Pulse Oxygen

Pulse oxygen (PO_2), the most important parameter used in ergospirometry, is defined as the volume of oxygen, which is extracted by the metabolism with each heart beat (VO_2/HR). This is dependent upon the provided blood volume and the absorption capacity of the tissues.[3,29] Despite its importance, none of the included studies assessed this parameter.

PROTOCOLS EMPLOYED TO EVALUATE CARDIORESPIRATORY PARAMETERS

Treadmill

This type of ergometer has some advantages in relation to others, since it requires higher metabolic demands, greater cardiac and metabolic stresses, and is an activity which better reflects performance, when compared with other ergometers[3] However, with stroke subjects, testing and training on treadmill can especially be hampered by the presence of spasticity and motor impairments of the trunk and lower limb muscles[33], and is also dangerous due to the risk of falls during test conditions.[10] Two studies used the treadmill for the assessment of cardiorespiratory parameters.[10,21] Da Cunha *et al.*[21] trained acute stroke subjects on a treadmill for 20 minutes daily with an initial speed of 0.01 m/s, which was increased in increments of 0.01 m/s, as prescribed by the therapists. Lee *et al.*[10] used the treadmill to assess maximal tests with acute, sub-acute, and chronic stroke subjects (mean time since the onset of stroke of 57 ± 54 months). The test speeds were established according to those the participants could support before the test was interrupted.

Cycloergometers

Cycloergometers are the preferred instruments for aerobic training with stroke subjects, since these individuals sometimes do not have the ability to walk at a speed required to promote adequate stresses of the cardiovascular system.[34] Twelve studies[10,12-19,22,24,29] used cycloergometers for training and assessment of cardiorespiratory fitness with protocols of various intensities and durations. However, it is reported that the maximum achieved VO_2 on the ergometer is usually 5 to 11% lower than that on the treadmill.[3,29]

Factors that influence the physical fitness after stroke

The cardiorespiratory fitness of stroke subjects is markedly impaired and dependent upon many factors, when the intrinsic characteristics of this disease are considered. According to Patterson *et al.*[35], adequate balance, cardiorespiratory fitness, and strength of the paretic lower limb are determinants for walking over short or long distances. These subjects have reduced aerobic function, which can be further exacerbated by the pre-existing cardiovascular diseases, such as hypertension, peripheral vascular diseases, metabolic or respiratory diseases[25].

The loss or decreases in physical capacity generates decreases in the frequency and intensity of physical activity, in connection with daily activities, leisure or work.[36] Additionally, the increased energy demands reduce the movement's intensity, favoring the decline in cardiorespiratory fitness and increasing weakness and disuse atrophy, which, in turn, lead to decreased function in stroke subjects.[37]

CONCLUSIONS

There were found large differences between the studies regarding the analyzed parameters and the assessment and training protocols, which make comparisons difficult. However, there was observed evidence that cardiorespiratory parameters, especially VO_2, are sensitive to training. Thus, ergospirometric assessment provides relevant data for the planning of interventions for stroke subjects, and therefore, could be used to further increase fitness levels in this population.

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