Maximal aerobic power in patients with chronic low back pain: a comparison with healthy subjects

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Abstract The objective of the study was to compare the maximal aerobic capacity of patients with chronic low back pain with healthy asymptomatic controls matched for age, gender and level of physical activity at work and during sports activities. Reported data in the literature with respect to aerobic capacity in patients with chronic low back pain are not conclusive. Nevertheless, based on the assumption that chronic low back pain leads to deconditioning, physical training programs are widely used as a treatment. A total of 70 patients with chronic low back pain and 70 healthy asymptomatic subjects completed questionnaires regarding demographics and performed a graded maximal exercise test until exhaustion on a cycle ergometer. The maximal aerobic power was measured by indirect calorimetry. Heart rate, respiratory exchange ratio and blood lactate levels were also measured. The test was considered maximal when VO_2max achievement criteria were obtained. VO_2max values were compared among groups. The absolute and normalized for weight values of VO_2max measured in patients with chronic low back pain were significantly lower than that of the control group. Independent comparison between men and women showed that absolute values of VO_2max are also significantly lower in men and women with chronic low back pain. Women reached absolute and normalized for weight VO_2max

values significantly lower than those of men, both in chronic low back pain and control group. In conclusion, chronic low back pain patients, especially women, seem to have a reduced aerobic capacity compared to healthy asymptomatic subjects.

Keywords Low back pain · Aerobic capacity · Functional restoration · Deconditioning

Introduction

Low back pain is, to date, a crippling health problem and its severity continues to increase in today's society. Low back pain leads to physical deconditioning by inactivity and consequently to a greater functional impairment constituting one of the most frequent causes of handicap. Low aerobic capacity has been associated with low back pain and is considered both a cause and consequence of chronic low back pain (CLBP) [21]. The diminishment of functional capacity has physiological and psychological implications that impair the subject's physical performance in the context of employment, sports practice and daily life [20]. In contrast, a high level of physical conditioning has demonstrated a protective role from low back pain and injuries in general [16].

Maximal oxygen uptake (VO_2max), considered nowadays the best parameter for the measurement of functional capacity both in healthy and ill subjects, is a very important variable in performing athletic, employment and daily living activities. Based on VO_2max measurements, Shvartz and Reibold [19] established categories of aerobic capacity matched for age and gender for individuals who were not highly trained. These categories are widely used by health professionals.

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Reported data in the literature with respect to aerobic capacity in patients with chronic low back pain (CLBP) are not conclusive [22] and range from low [11, 20, 25] to equivalents of active population [15, 18, 24]. Among the causes argued for the divergence in results are pain intensity [15], intensity of physical task during work and free time [24], and painful inhibition that makes performance difficult at maximal effort during the ergometric test [17]. Based on the assumption that patients with CLBP are deconditioned, a major goal in the treatment could be to combat the physiological effects of physical deconditioning through physical exercise under a functional restoration program. In fact, these physical training programs are widely used because they have demonstrated to date to be the best available therapeutic alternative [1].

Measurement of VO_2max by indirect calorimetry using gas analyzers while performing an effort until exhaustion is the most accurate way to determine the subject's maximal aerobic capacity. The accuracy in the measurement of this variable is very important when data are to be compared with other patient groups or with a reference population. The extrapolated value of VO_2max from submaximal efforts or its estimation using equations can overestimate or underestimate by up to 15% the VO_2max value in healthy subjects [4]. So far, few studies have subjected the patients with CLBP to ergometric tests to exhaustion using indirect calorimetry for the measurement of VO_2max . Although the gold standard for the maximal aerobic capacity measurement is the indirect measurement of VO_2 during maximal effort, few studies, have subjected patients with CLBP to ergometric tests until exhaustion. The most commonly used methods to estimate VO_2max in patients with CLBP are: physical working capacity index level [15], extrapolation of value from a submaximal test [18, 20], execution of a symptom-limited test [24] and execution of a graded continuous maximal exercise test [11].

In our study, we compared, using the indirect calorimetry method and taking into account the physiological and metabolic criteria of having achieved VO_2max during the ergometric test, data from CLBP patients with those of asymptomatic population matched for gender and age.

Methods

Two groups of subjects participated in the study: patients with CLBP referred from a rheumatology service of a teaching hospital and healthy asymptomatic subjects (control group). All subjects agreed to perform an exercise test until exhaustion in a bicycle ergometer. Prior to performing the test, each subject was sufficiently informed about the potential risks of test procedure and signed an informed consent. Before testing, all subjects were examined and

completed a questionnaire about demographics. During consultation, patients were diagnosed with specific or non-specific low back pain. Specific low back pain was defined by degenerative and congenital forms of stenosis as demonstrated by magnetic resonance imaging. Diagnostic criteria included the presence of short pedicles, facet joint osteophytes, ligamentous hypertrophy and disc protrusion. "Dark disc" was interpreted as the early stage of degeneration.

The inclusion criteria for CLBP patients were: diagnoses involving purely lumbar disorders, off work for at least for 4 months continuously, diagnosis of low back pain for at least 6 months with or without referred pain, absence of cardiopulmonary contraindications for heavy exercise, absence of musculoskeletal disabilities that would affect the ability to tolerate the test and the capacity to achieve the VO_2max during the test. All subjects were at least 18 years of age. Patients who failed in the performance of a maximal test and achieved a peak VO_2 value were excluded due to the need to consider only values of VO_2max . Data of submaximal tests would alter the estimate of the maximal aerobic capacity of the group.

Patients were asked to fill the Baecke's total physical activity score [5] and the Hamilton's anxiety score [9]. The first score was used to categorize from 1 to 4 the level of physical strenuousness at work and during sports activities (1 = very light to 4 = heavy), while the second score was used to evaluate the patient's functional and psychological aspects. Severity of back pain was assessed by means of the Main and Waddell's functional index [23]. Pain intensity was measured using a 100 mm-long visual analog scale [6] where 0 mm = no pain and 100 mm = the worst possible pain. Inclusion criteria for subjects of the healthy group were: adults without a sport practice more than twice a week, absence of medical history of chronic diseases or events related to cardiovascular health, normal resting ECG, unremarkable physical examination and achievement of a VO_2max value during ergometry. As in the group of patients with CLBP, asymptomatic subjects who failed in performing a maximal test and achieved a VO_2peak value were excluded.

All procedures were approved by the university institutional board for human subjects. Body weight and height were measured. Body mass was measured with a physician's balance scale (Detecto, Webb City Mo) to the nearest 0.1 kg. Body mass index (BMI) (kg/m^2) was calculated as the ratio of the subject mass to the height squared.

Testing

The exercise protocol consisted of a graded maximal exercise test until exhaustion with an initial stage at 30 W,

followed by a 30 W increase at each 3 min stage. A BOSCH ERG 550® (Switzerland) cycle ergometer was utilized and the pedaling rate was maintained at 60 rpm. Standardized instructions and encouragement were provided to obtain a maximum performance, defined as the temporary loss of strength and energy during the test. Expired air was analyzed using a Medical Graphics® Cardiopulmonary Exercise System CPX/D (St. Paul, MN, USA). The gas analyzers were calibrated immediately prior to each test session. All physiologic responses were determined at each 30-s interval throughout testing, and the average obtained during the last minute of each stage was used for data analysis. Electrical heart activity was monitored during the test with a SCHILLER® A.G. Cardiovit CS-200 (Switzerland) 12-lead electrocardiograph. Maximal heart rate was defined as the highest value recorded during the test and was divided by the predicted maximal heart rate ($220 - \text{age}$) to calculate the percentage of maximal heart rate achieved. Blood lactate level was measured using the enzymatic method [8]. Blood samples were obtained from the ear lobe after 5 min of rest in a recumbent position prior to the test, at the end of each stage during the test and following 5 min of recovery. Based on the review made by Howley et al. [12] concerning VO_2max achievement criteria, the test was considered maximal and VO_2max was considered valid when the subject achieved the primary criterion (variation $\leq 2 \text{ ml kg}^{-1} \text{ min}^{-1}$ with respect to the VO_2 value from the last test charge increment) or two of the three secondary criteria (lactatemia $\geq 6.7 \text{ mmol l}^{-1}$, respiratory exchange ratio ≥ 1.13 or maximal heart rate $\geq 90\%$ of the theoretical maximum). To normalize VO_2 values, VO_2max values were divided by body weight. Participants who failed to meet these criteria were dropped from the study.

Statistical analysis

Summary statistics were calculated for all variables. For the descriptive analysis, results are expressed as mean [standard deviation (SD)] and percentage. A proportion test was used to obtain percentage comparisons. A parametric test (Student's *t* test) was used for the comparison of means in independent groups (patients and control) and previous validation of suppositions (Kolmogorov–Smirnov normality test and homoscedasticity test). Student's *t* tests ($p < 0.05$) assessed differences between pairs of values. Database and statistical analysis were performed using the software SPSS 17.0 for Windows. SPSS Inc. 2008.

Results

A total of 171 subjects agreed to participate in this investigation, 101 with CLBP and 70 healthy subjects. Among

CLBP patients, 70 (69.3%) subjects achieved VO_2max criteria during the maximal cycle ergometer protocol and were included in the study. The remaining 31 patients who did not achieve VO_2max criteria were dropped from the analysis because of quadriceps/leg fatigue, exhaustion, maximal heart rate or low back pain. To configure the control group, we had a sampling frame of healthy subjects whose VO_2max had previously been established in the same laboratory, and who had met the criteria for VO_2max . To obtain a balanced sample between CLBP patients and the reference population, we randomly selected 70 healthy subjects: 37 male and 33 female. None of the participants had to interrupt the test prematurely because of chest pain or electrocardiographic modifications and/or signs of cardiac limitation. Comparison between those who did not and those who did achieve VO_2max criteria showed no significant difference regarding age, anthropometric parameters, pre-test severity of back pain or level of disability. Each group consisted of 37 men and 33 women. In the CLBP group of patients, 88% were diagnosed with specific low back pain [degenerative stenosis or intra-discal degeneration 83%, congenital (lumbar spinal stenosis) 6%, traumatic fracture 3%, degenerative spondylolysis 2%, other spinal stenosis 6%], while 12% were diagnosed with non-specific low back pain. There were no significant differences when ages and height of CLBP patients and healthy subjects were compared. Selected characteristics of population are shown in Table 1.

Percentages and mean values (SD) of anthropometric and demographic characteristics of patients with CLBP and healthy subjects included in the study and level of significance of comparison among groups and gender are shown in Table 1.

The absolute value of VO_2max measured in patients with CLBP was significantly lower than that of the control group ($p < 0.05$). Independent comparison between men and women showed that absolute values of VO_2max were also significantly lower in men and women with CLBP ($p < 0.05$ and $p < 0.001$, respectively). Women reached absolute values significantly lower than those of men both in CLBP and the control group ($p < 0.001$ and $p < 0.05$, respectively). The VO_2max value normalized for weight in patients with CLBP was also significantly lower than that of the control group ($p < 0.001$). Independent comparison among men and women showed that normalized for weight VO_2max values were also significantly lower in men and women of the CLBP group ($p < 0.001$). Women achieved values normalized for weight significantly lower than those of men both in CLBP patients and control groups ($p < 0.001$), respectively. Absolute and normalized for weight values of VO_2max obtained during ergometric tests are shown in Table 2.

Figure 1 shows the comparison of mean VO_2max ($\text{ml kg}^{-1} \text{ min}^{-1}$) values of patients with CLBP and control group.

Table 1 Percentages and mean values (SD) of anthropometric and demographic characteristics of subjects included in the study

Variable	All (<i>n</i> = 140)		Men (<i>n</i> = 74)		Women (<i>n</i> = 66)	
	CLBP (<i>n</i> = 70)	Control (<i>n</i> = 70)	CLBP (<i>n</i> = 37)	Control (<i>n</i> = 37)	CLBP (<i>n</i> = 33)	Control (<i>n</i> = 33)
Age (years)	39.1 ± 7.2	39.3 ± 7.1	38.9 ± 7.7	39.3 ± 7.8	39.7 ± 6.7	39.4 ± 6.9
Weight (kg)	68.6 ± 10.4*	65.8 ± 8.0	72.7 ± 7.7**	69.8 ± 5.5	64.0 ± 11.1	61.8 ± 8.5
Height (cm)	167.3 ± 7.8	164.4 ± 7.6	172.3 ± 6.5**	172.1 ± 5.2	161.9 ± 5.2	162.2 ± 5.2
BMI (kg/m ²)	24.5 ± 3.7*	23.5 ± 2.3	24.5 ± 2.3	23.6 ± 1.4	24.5 ± 4.8	23.4 ± 3.5
PSW (%)						
Light	5.5	3.4	3.7	1.5	8.1	4.2
Medium	28.5	29.4	14.8**	9.8**	48.6	50.1
Heavy	66.0	67.2	81.5**	88.7**	43.2	45.7
Pain intensity (VAS 100 mm)	51.7 (±23.8)		44.6 (±21.1)**		59.3 (±24.6)	
LBP duration (months)	69.4 (±57.2)		63.4 (±49.0)		76.2 (±64.6)	
Radicular pain (%)	63.3		58.4		41.6	
MOW (months mean ± SD)	12.0 (±8.6)		13.1 (±8.7)		10.9 (±8.6)	
PBS (%)	21.7		11.9		9.9	
MWFI (0–9)	3.9 (±2.3)		3.5 (±2.2)		4.3 (±2.4)	
HAS (0–56)	8.5 (±8.4)		5.9 (±9.2)		11.1 (±7.6)	

Values are means ± SD

CLBP chronic low back pain; BMI body mass index; PSW physical strenuousness at work; VAS Visual Analog Scale; LBP low back pain; MOW months off work; PBS previous back surgery; MWFI Main and Waddell's Functional Index; HAS Hamilton's Anxiety Score

* Statistically significant among groups

** Statistically significant among sexes

Table 2 Absolute and normalized for weight values of VO₂max obtained during ergometric tests

VO ₂ max value	All (<i>n</i> = 140)		Men (<i>n</i> = 74)		Women (<i>n</i> = 66)	
	CLBP (<i>n</i> = 70)	Control (<i>n</i> = 70)	CLBP (<i>n</i> = 37)	Control (<i>n</i> = 37)	CLBP (<i>n</i> = 33)	Control (<i>n</i> = 33)
l min ⁻¹	2.17 ± 0.65*	2.45 ± 0.50	2.58 ± 0.56**	2.82 ± 0.4**	1.72 ± 0.41	2.10 ± 0.4
ml kg ⁻¹ min ⁻¹	30.8 ± 7.7*	37.0 ± 7.0	33.9 ± 6.75**	40.5 ± 5.5**	22.7 ± 7.27	33.1 ± 6.6

Values are means ± SD

* Statistically significant among groups

** Statistically significant among sexes (*p* < 0.05)

Fig. 1 Means of normalized for weight values of VO₂max obtained during ergometric tests in both groups of patients [The artwork of Fig. 1 was created with GraphPad Prism® version 4 graphics program. (© 1994–2003, GraphPad Software Inc.)]

Comparison between groups of subjects and between sexes of data concerning percentage of theoretical maximal heart rate and respiratory exchange ratio did not demonstrate statistically significant differences. Additionally, we compared the pedaling maximal absolute power output performed during the test and the values of the physiological variables considered as a parameter of VO₂max achievement. The measured values of these variables are presented in Table 3.

Discussion

We found that, compared with the asymptomatic population matched for gender and age, patients with chronic low back pain has a significantly lower aerobic capacity. The

Table 3 Mean (SD) values of variables measured during the tests

Variable	All (<i>n</i> = 140)		Men (<i>n</i> = 74)		Women (<i>n</i> = 66)	
	CLBP (<i>n</i> = 70)	Control (<i>n</i> = 70)	CLBP (<i>n</i> = 37)	Control (<i>n</i> = 37)	CLBP (<i>n</i> = 33)	Control (<i>n</i> = 33)
MPO (W)	148.2 ± 38.9*	167.5 ± 40.9	174.1 ± 27.4**	198.6 ± 26.8**	119.1 ± 27.8	132.6 ± 20.5
% MHR	98.8 ± 6.9	99.7 ± 1.9	98.4 ± 8.6	99.9 ± 2.3	98.4 ± 8.6	99.9 ± 2.3
RER	1.11 ± 0.06	1.12 ± 0.13	1.13 ± 0.16	1.12 ± 0.04	1.10 ± 0.06	1.12 ± 0.10
[La _{max}] (mmol l ⁻¹)	8.52 ± 2.21	8.69 ± 2.27	9.29 ± 2.07**	8.62 ± 2.72	7.74 ± 2.1**	8.76 ± 1.70

Values are means ± SD

MPO maximal power output; %MHR percentage of theoretical maximal heart rate; RER respiratory exchange ratio; [La_{max}] maximal lactate

* Statistically significant among groups

** Statistically significant among sexes in CLBP patients

independent comparison of men and women in both groups reveals the same finding. These findings are consistent with those observed by Smeets et al. [20], Wittink et al. [25] and Hoch et al. [11] who reported lower VO₂max values in patients with CLBP than those of the reference population. By comparing the mean values of VO₂max of men and women with CLBP with normative data obtained from men and women not highly trained and proposed by Shvartz and Reibold [19], we found that men with CLBP were situated in the category “fair”, while women with CLBP fell into the “very poor” aerobic conditioning category. Although some authors consider that the reduction in VO₂max with physical inactivity is independent of age and gender [7] and others report that women have values of VO₂max greater than those of men due to cultural factors (childcare and household tasks) that make them more active [15, 24], none of these is the case in our study. We expected women with CLBP to have a lower VO₂max than men (similar to the difference between men and healthy men and women). These subjects were, in fact, categorized as “very poor” according to Shvartz and Reibold [19], a lower category than men with CLBP. This difference could be explained by a more restricted physical activity compared to men. This diminishment in physical activity could be due to a greater perception of back pain intensity, as demonstrated by its measurement using visual analog scale. Another possible explanation is the difference in physical strenuousness at work. More men than women perceived the physical strenuousness of their work as “heavy”, while more women than men perceived work strenuousness as “medium”. Additionally, we found that body mass index was significantly increased in patients with CLBP. From a public health perspective, this association has been previously described in the literature [10] demonstrating a link between overweight and low back pain. Increased mechanical demands resulting from obesity have been suspected to cause low back pain and, in this case, this finding can be secondary to a diminished level of physical activity. Finally, the nature and severity of spinal changes

responsible for specific low back pain could contribute to the poor VO₂max value achieved.

Regarding the control group, we consider that its aerobic capacity is in line with categories proposed by Shvartz and Reibold [19] in healthy, but not highly trained, subjects. In fact, our men and women were placed in the category “medium” of aerobic conditioning, confirming that the reference data in our study correspond as expected in a normative population.

Our study is not the first to compare patients with CLBP with asymptomatic controls matched for gender and age, but is the first to use an exercise protocol until exhaustion during ergometry, controlling physiologically and metabolically the achievement of VO₂max. Most of the previous studies used extrapolated values from a submaximal exercise test to estimate VO₂max [20, 21, 24, 25]. Other authors calculated predicted VO₂max values [18] or determined a fitness index [15].

One of the strengths, perhaps the most important one, in our study is the use of an incremental test until exhaustion using the method of indirect calorimetry that gives more accurate VO₂max values than those provided by nomograms and prediction equations as demonstrated by Astrand and Rodahl [3]. Another strength of our study is the comparison between groups. In fact, we compared maximum values of VO₂max among patients with CLBP and healthy subjects matched for age and gender from the same community, which was verified physiologically and metabolically. However, it is difficult to know to what extent the poor performance of patients with CLBP in the cycle ergometer is due to a low cardiorespiratory fitness or to the interference of back pain. It is true that pain, motivation and fear can affect the validity and reliability of maximal tests [14]. That is why in our study, we included only subjects who physiologically and metabolically performed a full test. Otherwise, the actual level of aerobic capacity could be underestimated.

So far, a variety of tests has been used to establish aerobic capacity in patients with CLBP, each with a

different methodology and without the existence of standardization to date. In reviewing the literature, we found that in the studies of Wittink et al. [24] and Hurri et al. [13], the levels of aerobic fitness in patients with CLBP were comparable with those of healthy persons. A reduced aerobic fitness level in CLBP patients compared with the normative population was reported by Nielens and Plaghki [15], Smeets et al. [20] and Van der Velde and Mierau [21]. Finally, Van der Velde and Mierau [21], estimating the aerobic capacity by means of a submaximal step test in patients with CLBP, found also that they had statistically significant lower levels of aerobic capacity than a large control group. Probably, the problem of conflicting results is due to the method used to measure VO_2max .

The level of aerobic fitness determines one's quality of life to the extent that adequate fitness allows one to perform activities of daily living. A long-term pain-induced inhibition of physical activity like that induced by chronic low back pain leads to further deconditioning affecting mainly cardiovascular and respiratory capacity. This deconditioning can perpetuate the sensation of pain and create a vicious cycle from which the patient may never escape.

Strong evidence exists for the effectiveness of exercise therapy in conservative treatment of CLBP. Accurately assessing the maximal oxygen consumption by using appropriate equipment and test protocols is crucial for an adequate prescription of training loads in both CLBP patients and healthy subjects, as recommended by the American College of Sports Medicine [2]. Although testing patients systematically to exhaustion may not be practical in patients with CLBP, this study accurately established the VO_2max in this population, allowing a grouping of subjects by category and ensuring a proper comparison between groups. The study should, therefore, contribute to the development of training programs facilitating an optimal response to the functional restoration program and preventing injuries during the development of these programs. At any rate, the results of cross-sectional studies must be treated carefully in terms of drawing conclusions of causality.

In conclusion, we found that maximal aerobic capacity was significantly lower in the CLBP patients group, and that women were significantly more deconditioned than men. These findings can be explained by the fact that back pain in general leads to physical deconditioning from inactivity and that women are less active and perceive greater pain than men. Future studies should make a longitudinal approach of VO_2max in patients who develop low back pain with progression to chronicity.

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