Acta Scientific MEDICAL SCIENCES (ISSN: 2582-0931)

Volume 6 Issue 1 January 2022

Review Article

Does Physical Deconditioning in Chronic Low Back Pain Exist? A Systematic Review

Ivan PJ Huijnen[1,2]*, Bart C Bongers[3,4], Bart CA Pepels[1], Harriet M Wittink[5], Jeanine A Verbunt[1,2] and Rob JEM Smeets[1,6]

[1]Department of Rehabilitation Medicine, Care and Public Health Research Institute (CAPHRI), Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands

[2]Adelante Center of Expertise in Rehabilitation and Audiology, Adelante Rehabilitation Center, Hoensbroek, The Netherlands

[3]Department of Epidemiology, Care and Public Health Research Institute (CAPHRI), Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, the Netherlands

[4]Department of Nutrition and Movement Sciences, Nutrition and Translational Research in Metabolism (NUTRIM), Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands

[5]Research Group Lifestyle and Health, Utrecht University of Applied Sciences, Utrecht, The Netherlands

[6]CIR Revalidatie, Eindhoven, The Netherlands

***Corresponding Author:** Ivan Huijnen, Department of Rehabilitation Medicine, Maastricht University, The Netherlands.

Received: September 25, 2021

Published: December 20, 2021

Abstract

The primary aim of this systematic review was to critically appraise the different methodologies used in studies to evaluate aerobic capacity in patients with chronic low back pain (CLBP). The second aim was to evaluate whether aerobic capacity of patients with CLBP differs from aerobic capacity of healthy age- and sex-matched subjects.

PUBMED, EMBASE, Web of Science, PEDro, and Cochrane databases were searched. A critical appraisal was performed on methodological quality of the used protocols using a self-designed assessment list.

A total of 28 studies were included in this review. Eleven studies (39.3%) used maximal exercise testing and seventeen studies (60.7%) used submaximal exercise testing. Large differences exist concerning the used exercise test protocols and methodologies to assess aerobic capacity of patients with CLBP. Similarly, large differences were found in how aerobic capacity of patients with CLBP was compared with age- and sex-matched healthy controls. Based on the results of the included studies, most studies found a lower aerobic capacity in patients with CLBP compared with age- and sex-matched healthy controls.

It can be concluded that it is not clear whether deconditioning is present in patients with CLBP. There are several points that warrant cautiousness before drawing a definitive conclusion.

Keywords: Chronic Low Back Pain; Aerobic Capacity; Physical Fitness; Exercise Testing

Abbreviations

ACSM: American College of Sports Medicine; CLBP: Chronic Low Back Pain; VO_{2max}: Maximal Oxygen Uptake

Introduction

The deconditioning paradigm still remains a topic of debate in chronic low back pain (CLBP) research and clinical practice [1]. Physical exercise therapy is recommended to improve physical functioning of patients with CLBP [2]. However, various mechanisms to improve physical functioning are proposed in trials [3] but the effects of exercise therapy to improve physical functioning were found to be only modest at best [2]. Attention gradually shifted to the biopsychosocial model to explain the persistence of pain. For example, the fear avoidance model assumes that patients avoid potentially harmful activities due to catastrophic thoughts [4]. This avoidance behavior may lead to disuse. Performing at a reduced daily physical activity level may result in deconditioning, mostly defined as a decreased level of physical fitness [5]. Physical fitness is an umbrella term containing, among other things, aerobic capacity and muscle strength. In patients with CLBP, little evidence has been found for deconditioning when related to muscle strength [1,5,6], and although several studies investigated aerobic capacity, deconditioning as reflected by a low aerobic capacity has not been systematically evaluated yet.

A challenge when evaluating results of studies reporting aerobic capacity in patients with CLBP is that a wide variety of tests and protocols have been reported. Maximal cardiopulmonary exercise testing, during which the subject continues exercising against a progressively increasing work rate until volitional exhaustion, is considered the gold standard to measure aerobic capacity, of which maximal oxygen uptake (VO_{2max}) is considered the single best measure [7]. For a proper interpretation of a maximal cardiopulmonary exercise test, it is of utmost importance to verify whether or not the patient delivered a true maximal effort as not all patients with CLBP complete this test up to the point of volitional exhaustion [8-10]. Submaximal exercise testing protocols have been used as a more feasible and less expensive alternative to estimate aerobic capacity. The rationale of these protocols is mostly based on the assumed linear relation between heart rate and oxygen uptake at two or more work rates [11,12]. However, maximal cardiopulmonary exercise testing protocols are preferred as they measure, rather than estimate, aerobic capacity [13], and are thus more precise.

Systematically evaluating the literature on the quality of the aerobic capacity test protocols as used during testing, and the methods used to verify a patient's effort, is essential to evaluate whether deconditioning is present in patients with CLBP. The latter is of considerable importance, as physical deconditioning is a reason to initiate reconditioning programs to improve a patient's aerobic capacity. Therefore, the aim of this systematic review was twofold. The first aim was to critically appraise the methodologies used in studies to evaluate aerobic capacity in patients with CLBP. The second aim was to evaluate whether aerobic capacity of patients with CLBP differs from aerobic capacity of healthy age- and sex-matched subjects.

Methods

The review has been executed according to the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and is registered in the PROSPERO register as: CRD42015015095.

Information sources and search strategy

PubMed, EMBASE, Web of Science, PEDro, and Cochrane databases were searched using medical subject heading (MeSH) terms and free text words (or synonyms) for: "low back pain" (population) AND "Exercise test" (intervention) AND "aerobic capacity" OR "physical fitness" (outcome) from inception to May 2020. Study selection was performed by two independent reviewers. If these reviewers did not reach consensus, a third reviewer was consulted. Reviewers were not blinded to data referring to the origin of the study. Study selection was performed in two steps. In the first step, studies were selected based on title and abstract. In the second step, a full text review of the potentially relevant studies was performed. Furthermore, the reference lists of all included studies were screened to check for missing relevant studies. Finally, missing studies known to the authors were included in the selection process.

Study selection

The inclusion criteria of this systematic review were: 1) the age of participants in the studies should be ≥18 years; 2) primary or secondary study outcomes involved aerobic capacity of patients with CLBP; 3) the study involved patients reporting low back pain ≥3 months without any specific cause such as a malignant tumor, infection, or fracture. In case a study evaluated aerobic capacity in a group of patients with heterogeneous chronic pain diagnoses consisting for <75% of patients with CLBP, and data were not separately reported for the group with CLBP, the involved authors were contacted and asked to provide data of patients with CLBP. If these data were or could not be provided, the study was excluded from the review. If a study assessed the effects of an intervention on aerobic capacity in patients with CLBP, only baseline data were included.

Critical appraisal

To assess the methodological quality of the used test protocols and to identify potential sources of confounding and bias, a critical appraisal list was designed (see supplementary file). The critical appraisal list was developed and peer-reviewed by all co-authors with experience and knowledge about clinical exercise testing to assess aerobic capacity in patients with CLBP. The survey was piloted in a semi-structured process using written and verbal feedback of the assessors. The critical appraisal list was evaluated on the number, relevance, scoring, and wording of the items, and whether the items captured all relevant aspects concerning clinical exercise testing to assess aerobic capacity. An assessment of specific potential sources of bias enabled us to discuss the strengths and weaknesses of the methods used. See appendix for the complete assessment list and scoring. The critical appraisal list consists of 11 items to score risk of bias and/or confounding. Two items are only scored in case of a maximal cardiopulmonary exercise test protocol, as these items ("criteria to confirm a 'true' VO_{2max}" and "patient encouragement") are not applicable for a submaximal exercise test. Since not every item has the same impact on the overall risk of bias and/or confounding, no cumulative score was given, which meets the recommendations for developing tools assessing risks of confounding and bias [14,15]. For items 1, 5, 9, and 11, 'low risk' or 'high risk' of confounding and bias can be scored, whereas 'low risk', 'moderate risk', or 'high risk' of confounding and bias can be scored for item 4, 6, and 8. Finally, for item 2, 3, 7, and 10, 'low risk', 'moderate risk', 'moderate-to-high risk', and 'high risk' of confounding and bias can be scored. Two reviewers performed the critical appraisal. In case of disagreement, a third reviewer was consulted in order to reach consensus.

Data extraction

The main outcome variable aerobic capacity was extracted by one reviewer and checked by a second reviewer. The additionally extracted data, if available, were the number of included subjects, sex, age, anthropometric characteristics, duration and severity of complaints (disability and physical activity level), and the used exercise protocol. In case of reporting separate data for subgroups of patients with CLBP, a pooled mean and standard deviation was calculated using a Java-script based statistical tool [16].

Results

Study selection

The literature search identified 1080 unique studies and three additional studies were identified after checking reference lists of selected studies. Of these 1080 studies, 87 were selected based on title and abstract. Full text reading resulted in the exclusion of 59 studies. Finally, a total of 28 studies were included in the review (see Figure 1 for the flow chart). Eleven studies (39.3%) used a maximal exercise test [10,17-26] and 17 studies (60.7%) used a submaximal exercise test [8,9,27-41] to assess aerobic capacity in patients with CLBP. Although two studies of Duque., *et al.* [10,21] used the data from the same patient population, the results of patients with CLBP in both studies were compared with two different control groups. In their first study, age- and sex-matched norm values were used as reference group [21], whereas they included an age- and sex-matched control group in their second study [10]. Therefore, both studies were scored using the critical appraisal.

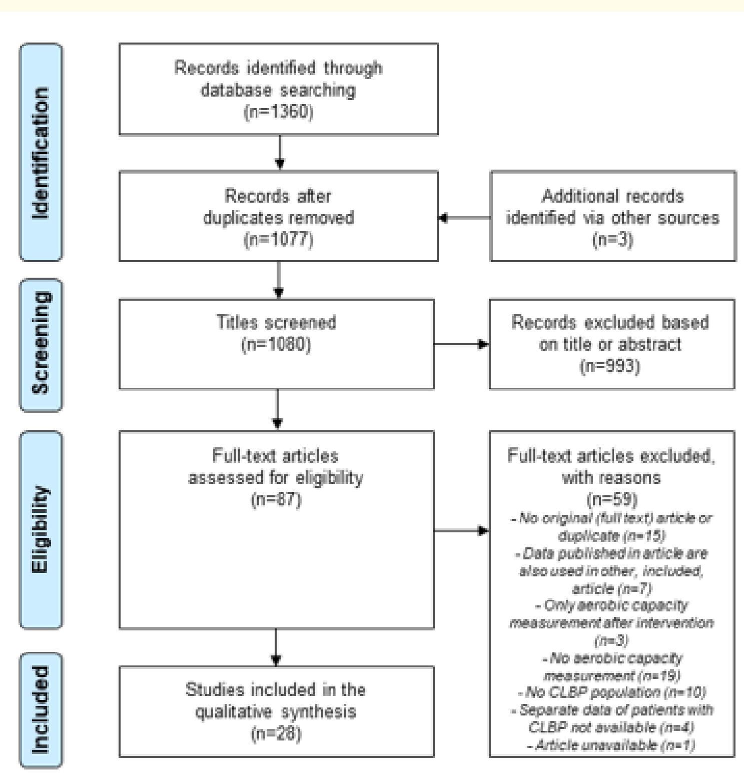

Figure 1: PRISMA flowchart for the selection of studies.

Many different exercise test protocols were used for measuring or estimating aerobic capacity. Maximal exercise tests were performed using a treadmill (e.g., the Bruce protocol [24], the modified Bruce protocol [17,19], or other maximal treadmill protocols [22]), or by using cycle ergometry [10,18,20,21,23,25,26]. In five studies using a submaximal exercise test protocol, participants performed the original Åstrand test protocol [27,32,35,37,41], whereas participants in five other studies performed a modified version of the Åstrand test protocol [9,28-30,39].

Critical appraisal

Results of the critical appraisal are presented in Table 1 and the key for scoring is presented in the supplementary file. Two of the eleven studies (18.2%) using a maximal cardiopulmonary exercise test protocol scored >50% of the 11 items as 'low risk' [10,21]. No study using a maximal exercise test scored 'low risk' on item 7 addressing criteria used to confirm a 'truly' measured VO_{2max}. Four of the 17 studies (23.5%) using a submaximal exercise test protocol scored >50% of the items as 'low risk' [9,30,35,39]. None of the included studies using a submaximal exercise test scored 'low risk' on all 9 items.

Results of studies using maximal cardiopulmonary exercise tests

Table 2 presents the results of the eleven studies using maximal cardiopulmonary exercise testing to measure aerobic capacity in patients with CLBP. Only in one of the two studies of Duque., *et al.* [10] and the study of Hoch., *et al.* [22] (18.2%), an age- and sex-matched pain free control group was included. Both studies found a significantly lower aerobic capacity in patients with CLBP compared to healthy controls. In the study of Hoch., *et al.* [22], scoring 4/11 items of the critical appraisal as low risk for bias, only female patients with CLBP and controls were included. In this study however [22], the mean score on the Oswestry disability index was 19.0 (13.3), indicating that patients were only minimally disabled [42,43], and in the study of Duque., *et al.* [10] the mean disability level of the patients was 3.9 on a 0-9 scale, with 0 indicating no disability and 9 indicating a high level of disability. The study of Duque., *et al.* [10] scored 8/11 items as low risk for bias (72.7%).

In five studies, aerobic capacity of patients with CLBP was compared with a normative dataset of healthy controls [18-21,25]. One study scoring 3/11 items as low risk for bias (27.2%) compared the results of patients with CLBP with a healthy age- and sex-matched reference group and concluded that patients with CLBP had a lower aerobic capacity; however, the disability or physical activity level was not reported [20]. The other study of Duque., *et al.* [21], scoring 7/11 items as low risk for bias (63.6%), concluded that patients with CLBP had a similar aerobic capacity as a healthy but poorly conditioned reference group. One study scoring only 1/11 items as low risk for bias, stated that patients with CLBP (only males) had 70% of the mean maximal workload capacity compared to a healthy control group [18], indicating a below normal work rate capacity for patients with CLBP compared to healthy middle aged men [44]. However, no further specification of the latter group was provided and also the disability or physical activity level was not reported. Another study [19] scoring 4/11 items as low risk for bias found that 43.5% and 47.8% of the included patients with CLBP scored below the 50th percentile of sex- and age-related percentile values for aerobic capacity without reporting the disability or physical activity level [19,45]. This indicates that more than 50 percent of the included patients in both arms of the trial scored above the 50th percentile of the American College of Sports Medicine (ACSM) standards. In three studies (33.3%), no comparison was

Name first author and year of publication	Item 1: Exclusion in case of contra-indications for exercise testing (1 or 4)	Item 2: Comparable reference or control group based on sex, age, body mass and level of physical activity (1, 2, 3, or 4)	Item 3: Participant characteristics and main outcomes of patients and control group (1, 2, 3, or 4)	Item 4: Description of specific CLBP population characteristics (1, 2, or 4)	Item 5: Description of adverse events and early test termination (1 or 4)	Item 6: Pretest instructions (1, 2, or 4)	Item 7: Criteria to confirm a 'truly' measured VO_{2max} (1, 2, 3, or 4)	Item 8: Description of variable(s) used for determination of VO_{2max} (1, 2, or 4)	Item 9: Description of exercise test protocol (1 or 4)	Item 10: Validity and test-retest reproducibility of the test protocol and calibration procedures of the physiological testing equipment (1, 2, 3, or 4)	Item 11: Patient encouragement (1 or 4)
Atalay 2012 [17]	4	4	4	4	4	4	4	4	4	4	4
Bachynski-Cole 1985 [18]	4	4	4	4	4	4	4	4	1	4	4
Brox 2005 [27]	4	3	2	1	4	4	NA	4	4	4	NA
Chan 2011 [19]	1	3	1	1	4	4	4	2	1	4	4
Doury-Panchout 2012 [20]	1	3	3	1	4	4	4	2	1	4	4
Duque 2009 [21]	1	4	1	1	1	4	2	1	1	4	1
Duque 2011 [10]	1	1	1	1	1	4	2	1	1	4	1
Hoch 2006 [22]	1	3	2	1	4	2	4	1	1	4	4
Hodselmans 2001 [30]	4	4	3	1	4	4	NA	4	1	4	NA
Hodselmans 2008 [28]	1	4	2	1	1	4	NA	1	1	3	NA
Hodselmans 2010 [29]	4	1	2	2	4	4	NA	1	1	3	NA
Hurri 1991 [31]	1	3	3	2	4	4	NA	2	1	3	NA
Kell 2009 [23]	1	4	1	1	4	4	2	2	1	4	1
Keller 2001 [32]	4	2	2	2	4	2	NA	1	1	4	NA
Koldas Dogan 2008 [24]	1	4	3	1	4	4	4	4	4	4	4
McQuade 1988 [33]	4	4	3	1	4	4	NA	4	4	4	NA
Protas 2004 [34]	1	4	3	1	4	4	NA	1	1	4	NA
Rasmussen-Barr 2008 [35]	1	1	1	1	1	2	NA	2	1	1	NA
Robert 1995 [36]	1	4	1	4	1	4	NA	1	4	2	NA
Smeets 2009 [9]	1	1	1	1	1	2	NA	1	1	1	NA

Storheim 2000 [37]	4	4	1	1	4	4	NA	4	4	4	NA
Van der Velde 2000 [38]	4	3	2	1	4	4	NA	4	4	3	NA
Verbrugghe 2019 [26]	4	4	1	1	4	4	2	4	1	4	4
Verbrugghe 2020 [25]	1	4	2	1	1	4	4	4	1	4	4
Verbunt 2003 [39]	1	4	1	1	1	4	NA	1	1	2	NA
Wallbom 2002 [40]	4	4	2	1	4	4	NA	1	1	4	NA
Wittink 2000 [8]	4	1	2	4	1	4	NA	1	4	1	NA
Wormgoor 2008 [41]	1	2	2	1	4	4	NA	1	4	3	NA

Risk of confounding and bias: 1= Low Risk; 2= Moderate Risk; 3= Moderate to High Risk; 4= High Risk.
Items 1, 5, 9, and 11: score 1 or 4.
Items 4, 6, and 8: score 1, 2 or 4.
Items 2, 3, 7, and 10: score 1, 2, 3 or 4.
Items 7 and 11 are only scored in case of a maximal exercise test; in case of a submaximal exercise test, item is scored as not applicable.
Abbreviations: CLBP= Chronic Low Back Pain; NA= Not Applicable; VO_{2max}= Maximal Oxygen Uptake.

Table 1: Critical appraisal.

Name first author and year of publication	Number of subjects	Age in years (SD)	Anthropometrics (SD)	Duration of complaints (SD)	Disability level and physical activity level (SD)	Test protocol	VO_{2max} (SD)	Conclusions
Atalay 2012 [17]	20 patients with CLBP: 6 males, 14 females	52.0 (6.4)	BMI: 5 patients in normal range (<25 kg/m^2), 9 patients between 25 and 30 kg/m^2, 6 patients between BMI 30 and 40 kg/m^2	123.6, ranging from 12 to 408 months	Disability: Not reported Physical activity: Not reported	CPET on a treadmill, modified Bruce protocol (modification not specified).	Pooled data [16]: 22.6 (4.9) mL/kg/min; patients were classified based on facet degeneration as assessed using 1.5 Tesla MRI. Patients with Weishaubt facet degeneration grade 1 and 2: 24.13 (5.13) mL/kg/min; patients with facet degeneration type 3: 19.15 (4.15) mL/kg/min	Similar aerobic capacity in male and female patients with CLBP and between patients with radicular and non-radicular pain. More facet degeneration was associated with a lower aerobic capacity (r=-0.5; p = 0.025)
	Controls: No control group							
Bachynski-Cole 1985 [18]	9 patients with CLBP: 9 males	37.2 (11.8)	Body mass: 86.0 (7.0) kg	Not reported	Disability: Not reported Physical activity: Not reported	CPET on a cycle ergometer, a maximal progressive test with work rate stages of 3 minutes. The increase in work rate was chosen so that subjects were able to finish the test within 6-12 minutes.	2.6 (0.3) L/min, 30.6 (5.1) mL/kg/min	Patients had only 70% of the maximal work rate capacity compared with healthy subjects in a cited study. [62] All subjects were able to perform the maximal exercise test to exhaustion.

	Controls: No control group							
Chan 2011 [19]	46 patients with CLBP: 10 males, 36 females, randomized in 2 groups					CPET on a treadmill, modified Bruce protocol in which the first two stages were performed at 2.74 km/h at 0% and 5%, respectively. As of the third stage (2.74 km/h at 10%) the original Bruce protocol was followed.		According to age- and sex-adjusted norm values from the Cooper institute, 43.5 and 47.8% of the subjects were ranked below the 50th percentile for VO_{2max}. [45]
	G1: 5 males, 17 females	46.0 (11.5)	Body mass: 58.5 (9.5) kg, BMI: 22.8 (2.9) kg/m^2	14.1 (21.5) months	Disability: ALBPDS: 30.8 (13.0) Physical activity: Number of patients participating at an average weekly level of physical activity: none 10, light 2, moderate 1, and vigorous 9		40.4 (6.9) mL/kg/min	
	G2: 5 males, 19 females	47.1 (8.3)	Body mass: 59.8 (8.5) kg, BMI: 23.5 (3.0) kg/m^2	11.9 (13.7) months	Disability: ALBPDS: 28.8 (11.0) Physical activity: Number of patients participating at an average weekly level of physical activity: none 14, light 3, moderate 4, and vigorous 13		39.0 (4.7) mL/kg/min	
	Controls: No control group							

Doury-Panchout 2012 [20]	71 patients with CLBP: 50 males, 21 females	42.3 (9.1)	BMI: 26.8 (5.4) kg/m^2	9.1 (7.1) months	Disability: Not reported Physical activity: Not reported	CPET on a cycle ergometer, a maximal progressive test was used, starting at 30 W and increasing with 30 W increments lasting three minutes each. The test was stopped due to exhaustion (indicated as submaximal test) or when the maximum heart rate was reached (maximal test).	Total group 21.6 mL/kg/min, males 24.3 mL/kg/min, females 19.4 mL/kg/min	No significant differences in aerobic capacity between patients with CLBP and other chronic pain conditions (patients with upper limb musculoskeletal disorders or patients with multifocal chronic pain) were found in this study. The authors compared the results of patients with CLBP with a healthy age- and sex-matched reference group and concluded that patients with CLBP had a lower aerobic capacity [63]. Of the total population, 58.1% did not perform a maximal test (maximum heart rate was <95% of the theoretical maximal heart rate). This percentage was not specifically reported for the group of patients with CLBP.
	Controls: No (pain-free) control group							
Duque 2009, 2011 [10, 21]	70 patients with CLBP able to perform a maximal exercise test: 37 males, 33 females	males: 38.9 (7.7), females 39.7 (6.7)	Body mass: males 72.7 (7.7) kg, females 64.0 (11.1) kg BMI: males 24.5 (2.3) kg/m^2, females: 24.5 (4.8) kg/m^2	males 63.4 months, females 76.2 months	Disability: MWI: 3.9 (2.3), males 3.5 (2.2), females 4.3 (2.4) Physical activity: Strenuousness at work (%), males: light 3.7%, medium 14.8%, and heavy 81.5%, females: light 8.1%, medium 48.6%, and heavy 43.2%	CPET on a cycle ergometer, an incremental discontinuous maximal test was used. Initial work rate was 30 W and each 3 minutes followed by a 30 W increase up to exhaustion. Between each stage there was a 1-minute rest stage.	Total group 2.2 (0.7) L/min, 30.8 (7.7) mL/kg/min, males 2.6 (0.6) L/min, 33.9 (6.75) mL/kg/min, females 1.7 (0.4) L/min, 22.7 (7.3) mL/kg/min	Authors indicate that aerobic capacity of patients with CLBP is interpreted as a similar aerobic capacity compared to a healthy but poorly conditioned reference group. [21] A total of 31 patients stopped the test because of quadriceps/leg fatigue, exhaustion, maximal heart rate, or low back pain. The patients who stopped the test did not differ regarding anthropometric parameters, severity or level of disability compared to the patients who were able to complete the test. Data from these patients were not used in the analysis.
Duque 2009 [21]	Controls: No control group							

Duque 2011 [10]	Controls: 37 males, 33 females (matched with patients, also reported in 2009 study)	males: 39.3 (7.8), females 39.4 (6.9)	Body mass: males 69.8 (5.5) kg, females 61.8 (8.5) kg BMI: males 23.6 (1.4) kg/m^2, females: 23.4 (3.5) kg/m^2		Physical activity: Male controls: light 1.5%, medium 9.8%, and heavy 88.7%, female controls: light 4.2%, medium 50.1%, and heavy 45.7%		Total group 2.45 (0.5) L/min, 37.0 (7.0) mL/kg/min, males 2.82 (0.4) L/min; 40.5 mL/kg/min, females 2.1 (0.4) L/min, 33.1 (6.1) mL/kg/min	When compared with healthy age- and sex-matched controls, it was found that patients with CLBP had a lower VO_{2max} ($p < 0.01$). [10] Male and female patients with CLBP had a lower aerobic capacity, both absolute and corrected for body mass, than healthy controls (respectively $p < 0.05$ and $p < 0.001$ for males and $p < 0.001$ and $p < 0.001$ for females).
Hoch 2006 [22]	21 female patients with CLBP	37.5 (7.4)	Body mass: 67.0 (14.7) kg; Body fat: 28.2 (4.0) %	Not reported	Disability: ODI: 19.0 (13.3) Physical activity: Weekly exercise frequency: 2.8 (0.9), duration in minutes per session: 37.6 (6), intensity (rating of perceived exertion) 12.4 (1.1)	CPET on a treadmill. The first stage was a 2.0 mph and 2.5% grade followed by 3.0 mph and grade 5.0%. The next stage was 3.0 mph and grade 10.0%. The first three stages were 4 minutes each. Next, the speed and graded are set on an individual basis to result in volitional fatigue in 4 to 6 minutes.	35.8 (8.0) mL/kg/min	Patients with CLBP (only females) had a lower aerobic capacity compared to controls ($p < 0.05$). The frequency (days/week) and duration (min/session) of exercise was significantly lower in patients with CLBP and might be related to the lower aerobic capacity. Controls scored at the 75th percentile of the norm values, indicated as good, and patients with CLBP scored at the 50th percentile of the norm values, indicated as fair. [48]
	Controls: 20 controls (females)	35.7 (7.5)	Body mass: 65.9 (13.7) kg Body fat: 24.2 (4.0) %		Physical activity: Not reported		40.6 (8.0) mL/kg/min	
Kell 2009 [23]	27 patients with CLBP: 16 males, 11 females randomized in 3 groups					CPET on a cycle ergometer, an incremental protocol in which the resistance for male subjects started at 1 kilopond per minute and for female subjects at 0.5 kilopond per minute, and every minute resistance was increased by 0.5 kilopond. Probably kilopond should be kilopond per kg body mass. The test was performed on a cycle ergometer with a pedaling frequency between 60 and 65 rotations/min up to maximal exhaustion.		No relevant conclusions can be drawn for this study.

	G1: 6 males, 3 females	40.1 (8.7)	Body mass: 88.4 (22.4) kg Body height: 1.74 (0.08) m	27.6, ranging from 6 to 96 months (all patients)	Disability: ODI: 40.4 (2.4) Physical activity: Godin leisure-time exercise survey: mean of 9.5, ranging from 6 to 22) indicating low physical activity level		32.2 (9.4) mL/kg/min	
	G2: 5 males, 4 females	36.7 (8.90)	Body mass: 81.7 (11.5) kg Body height: 1.73 (0.1) m		Disability: ODI: 39.8 (2.3) Physical activity: Godin leisure-time exercise survey: mean of 9.5, ranging from 6 to 22, indicating low physical activity level		34.5 (7.7) mL/kg/min	
	G3: 5 males, 4 females	35.3 (7.3)	Body mass: 87.4 (28.0) kg Body height: 1.70 (0.11) m		Disability: ODI: 39.2 (3.4) Physical activity: Godin leisure-time exercise survey: mean of 9.5, ranging from 6 to 22, indicating low physical activity level		34.8 (11.0) mL/kg/min	
	Controls: No control group							
Koldas Dogan 2008 [24]	60 patients with CLBP: 15 males, 45 females, randomized in 3 groups					CPET on a treadmill, Bruce protocol.		No relevant conclusions can be drawn for this study. Results of VO_{2max} are very low and seem VO_{2max} values in L/min. However, body mass data were not reported in the manuscript and not provided after requesting the author; therefore, it was not possible to recalculate VO_{2max} values to mL/kg/min.
	G1: 4 males, 15 females	37.1 (6.5)	Not reported	38.8 (56.7) months	Disability: Not reported Physical activity: Not reported		2.3 (0.6) mL/kg/min	
	G2: 4 males, 14 females	41.5 (8.3)		62.6 (81.0) months	Disability: Not reported Physical activity: Not reported		2.2 (0.5) mL/kg/min	
	G3: 4 males, 14 females	42.1 (9.5)		59.4 (61.5) months	Disability: Not reported Physical activity: Not reported		2.1 (0.6) mL/kg/min	

	Controls: No control group							
Verbrugghe 2019 [26]	38 patients with CLBP: 12 males, 26 females, randomized in two groups	44.1 (9.8)				CPET on a cycle ergometer, an incremental protocol in which the resistance for male subjects started at 30 W and was increased by 15 W/min up to maximal exhaustion, while for female subjects, resistance started at 20 W and was increased by 10 W/min up to maximal exhaustion.		No relevant conclusions can be drawn for this study, as VO_{2max} values were not presented separately for males and females. However, while taking the average age- and sex-distribution of the included population into account, VO_{2max} values would be classified as poor-to-fair compared to sex- and age-matched reference values. [46]
	G1: HIT: 6 males, 13 females	44.3 (8.8)	BMI: 25.6 (4.0) kg/m^2	141.6 (100.8) months	Modified ODI: 22.8 (9.4) PASIPD: 16.5 (10.6)		31.2 (9.3) mL/kg/min	
	G2 MIT: 6 males, 13 females	44.0 (11.0)	BMI: 25.9 (3.6) kg/m^2	123.6 (85.2) months	Modified ODI: 18.8 (9.2) PASIPD: 14.9 (11.7)		28.8 (8.0) mL/kg/min	
Verbrugghe 2020 [25]	101 patients with CLBP: 39 males, 62 females	44.2 (9.6)	BMI: 25.0 (3.7) kg/m^2	144.0 (105.6) months	Modified ODI: 21.1 (10.1) % PSFS: 42.5 (16.5) %	CPET on a cycle ergometer, an incremental protocol in which the resistance for male subjects started at 30 W and was increased by 15 W/min up to maximal exhaustion, while for female subjects, resistance started at 20 W and was increased by 10 W/min up to maximal exhaustion.	2.3 (0.7) L/min 31.8 (8.0) mL/kg/min	The authors concluded that patients had a fair VO_{2max} compared to sex- and age-matched reference values. [46] However, it is difficult to draw relevant conclusions, as VO_{2max} values were not presented separately for males and females. Patients scored rather low on disability level. Remarkably, all patients were able to perform a valid maximal effort on the cardiopulmonary exercise test.

Abbreviations: ALBPDS= Aberdeen Low Back Pain Disability Scale; BMI= Body Mass Index; CLBP = Chronic Low Back Pain; CPET= Cardiopulmonary Exercise Testing; HIT= High-Intensity Training; MIT= Moderate-Intensity Training; MRI= Magnetic Resonance Imaging; MWI= Main and Waddel's Functional Index; ODI= Oswestry Disability Index; PASIPD= Physical Activity Scale for Individuals with Physical Disabilities; PSFS= Patient Specific Functioning Scale; RPE= Rating of Perceived Exertion; SD= Standard Deviation; VO_2max= Maximal Oxygen Uptake.

Table 2: Results of aerobic capacity measured with a maximal exercise tests in patients with CLBP.

made between patients with CLBP and healthy controls [17,23,24]. A recent study [25] that included patients with CLBP with a rather low mean score on the Oswestry disability index of 21.1 (10.1), indicated that included patients can be categorized as having a fair aerobic capacity compared to sex- and age-related norm values [46].

Five studies (45.5%) reported whether patients were able to perform the maximal cardiopulmonary exercise test [10,18,20,21,25]. In one study, one out of nine patients (11.1%) did not perform with maximal effort [18], whereas in the two articles of Duque., *et al*. [10,21], 30.7% of the patients with CLBP stopped the maximal cardiopulmonary exercise test prematurely. In another study, values of a population consisting of patients with upper limb pain, multifocal chronic pain, and CLBP (45.8% of total population) were presented, but values regarding the percentage of patients stopping the test prematurely were not specifically presented for the patients with CLBP [20]. This study reported that only 41.9% could perform a valid maximal cardiopulmonary exercise test (maximum heart rate achieved during the test <95% of the predicted maximal heart rate). In the study of Verbrugghe., *et al*. [25], all patients were able to complete the maximal exercise test.

Two studies (18.2%) did not report the duration of pain complaints [18,22]. The other studies reported pain duration varying from 9.1 to 144.0 months [20,25]. Four studies (36.4%) did not report the disability or physical activity level of the included population [17,18,20,24]. Studies reporting the disability level used the Aberdeen low back pain disability scale [19], the Main and Waddel's functional index [10,21], and the Oswestry disability index [22,23,25,26].

Results of studies using submaximal exercise tests

Table 3 presents the results of studies that estimated aerobic capacity in patients with CLBP using a submaximal exercise test. In three of the 17 studies (17.6%), age- and sex-matched healthy controls were included [27,32,35]. Brox., *et al*. [27], scoring 1/9 items as low risk for bias on the critical appraisal, included a severely disabled patient population, and Rasmussen-Barr., *et al*. [35], scoring 7/9 items as low risk for bias, included a moderately disabled population. However, both studies did not find a significant difference in aerobic capacity between patients with CLBP and healthy controls [27,35]. Nevertheless, Rasmussen-Barr., *et al*. [35] found that female patients with CLBP had a significantly lower aerobic capacity compared to healthy female controls. Keller., *et al*. [32], scoring 5/9 items as low risk for bias, concluded that patients with CLBP had a significantly lower aerobic capacity compared to healthy controls, but did not report the disability or physical activity level.

Name first author and year of publication	Number of subjects	Age in years (SD)	Anthropometrics (SD)	Duration of complaints (SD)	Disability level and physical activity level (SD)	Test protocol	VO_{2max} (SD)	Conclusions
Brox 2005 [27]	45 patients with CLBP: 21 males, 24 females	37.5 (7.4)	Body mass: 75.6 (15.7) kg Body height: 172.0 (15.7) cm	Not reported	Disability: ODI: 43.5 (13.3) Physical activity: Not reported	The authors describe that they used the Åstrand test protocol; however, the referred study of Åstrand does not describe a specific protocol [64]	31.8 (8.6) mL/kg/min	A nearly statistically significant difference (p = 0.06) was found comparing aerobic capacity between patients with CLBP and healthy controls. Patients with subacute low back pain were also included in this study. Aerobic capacity of this group was similar to patients with CLBP, but differed statistically significant compared to healthy controls (p = 0.004).
	Controls: 45 controls, 21 males, 24 females	35.7 (7.5)	Body mass: 74.5 (10.8) kg Body height: 173.8 (10.8) cm		Disability: ODI: 1.6 (3.5) Physical activity: Not reported		34.7 (9.0) mL/kg/min	
Hodselmans 2001 [30]	24 patients with CLBP: 12 males, 12 females, randomized in 2 groups					Modified indirect Åstrand test protocol. The modification was that the work rate was determined on lean body mass. Patients started at a work rate of 0.5 W/kg lbm. After 2 minutes, work rate increased to 1.5 W/kg lbm, at which patients were required to cycle for 6 minutes.		No comparison with pain-free controls.

	Experimental group: 7 males, 7 females	38 (7.7)		Not reported	Disability: RDQ: 12.5 (6.9) Physical activity: Not reported		44.1 (9.1) mL/kg lbm/min	
	Control group: 5 males, 5 females	32 (8.1)			Disability: RDQ: 8.1 (4.0) Physical activity: Not reported		54.6 (18.4) mL/kg lbm/min	
	Controls: No pain-free control group							
Hodselmans 2008 [28]	20 patients with CLBP: 8 males, 12 females	33.8 (8.6)	Body mass: 73.9 (14.7) kg Body height: 1.76 (0.1) m	68.0 (ranging from 8.0 to 180.0) months	Disability: RDQ: 10.2 (5.3) Physical activity: Not reported	Modified indirect Åstrand test protocol. The modification was that the work rate was determined on lean body mass. Patients started at a work rate of 0.5 W/kg lbm. After 2 minutes, work rate increased to 1.5 W/kg lbm. If the heart rate remained <120 beats/min, the work rate was increased by 0.5 W/kg lbm every 2 minutes. Once the heart rate was >120 beats/min, the patient cycled 6 minutes on a fixed work rate to reach steady state, meaning that heart rate did not vary more than ±5 beats/min during the final 2 minutes of exercise.	Mean VO_{2max} (2 measurements, n = 18), 2.7 (0.9) L/min, 36.9 (11.9) mL/kg/min, 49.7 (12.6) mL/kg lbm/min	Aerobic capacity of patients with CLBP was significantly lower than (younger) movement sciences students for both absolute as relative to body mass and lean body mass (respectively $p < 0.014$, $p < 0.005$, and $p < 0.045$). One patient (5%) stopped the test prematurely due to fatigue and pain and the result of one patient was presented as a possible outlier.
	Controls: 20 controls, 10 males, 10 females	22.0 (1.6)	Body mass: 72.4 (8.5) kg Body height: 1.79 (0.1) m		Physical activity: Not reported		3.5 (1.0) L/min, 48.6 (11.6) mL/kg/min, 58.3 (12.8) mL/kg lbm/min	

Hodselmans 2010 [29]	101 patients with CLBP: 55 males, 46 females	39.2 (9.6)	Body mass: 81.9 (15.5) kg Body height: 174.0 (9.0) cm	64.1 (68.4) months	Disability: Not reported Physical activity: Sport activity per week: n = 53 <1 hour, n = 36 1-2 hours, n = 12 3-6 hours	Modified indirect Åstrand test protocol. The modification was that the work rate was determined on lean body mass. Patients started at a work rate of 0.5 W/kg lbm. After 2 minutes, work rate increased to 1.5 W/kg lbm. If the heart rate remained <120 beats/min, the work rate was increased by 0.5 W/kg lbm every 2 minutes. Once the heart rate was >120 beats/min, the patient cycled 6 minutes on a fixed work rate to reach steady state, meaning that heart rate did not vary more than ±5 beats/min during the final 2 minutes of exercise.	2.5 (0.6) L/min, 32.1 (7.3) mL/kg/min, 45.7 (9.6) mL/kg lbm/min (all n = 91)	Patients with CLBP had a lower aerobic capacity normalized for body mass and lean body mass (both $p < 0.001$) compared to sex-, age-, and physical activity-matched normative controls based on a Dutch database [65].
	Controls: No control group							
Hurri 1991 [31]	245 patients with CLBP: 174 males, 71 females	Males 44.1, females 45.6	Not reported	Males 13.3 years, females 9.9 years	Disability: Not reported Physical activity: Not reported	An incremental bicycle test was used. The initial work rate was 25 W and each 4 minutes a 25 W increase was applied up to subjective maximum or interruption for medical reasons. From two to three submaximal work rates heart rate frequency was used to estimate VO_{2max}.	Males 2.7 (0.5) L/min, 33.7 (6.4) mL/kg/min, females 2.1 (0.4) L/min, 30.0 (6.7) mL/kg/min	Patients with CLBP included from a population of physically strenuous or moderately strenuous workers had a similar aerobic capacity compared to sex- and age-matched Czechoslovak normative controls [66].
	Controls: No control group							

Keller 2001 [32]	31 patients with CLBP: 7 males, 24 females	36 (30-42.5), median (quartiles)	Body mass: 68.0 (61.0-74.0) kg, median (quartiles) BMI: 22.3 (21.5 - 25.5) kg/m^2, median (quartiles)	4.0 (1.4-10.0) years, median (quartiles)	Disability: Not reported Physical activity: Not reported	The Åstrand test protocol [11]0 The work rate was set within the first 2 minutes and aimed to reach a heart rate >120 beats/min. The test lasted for 6 minutes. If heart rate changed more than ±4 beats/min, the test continued with 1-minute increments until a steady state was obtained. If the heart rate had not reached >120 beats/min, or if it was too high, the test was stopped.	Three tests performed. Results of the first test were 36 (32-46) mL/kg/min, median (quartiles)	Patients with CLBP had a lower aerobic capacity compared to age-, sex-, and body mass-matched controls ($p < 0.001$).
	Controls: 31 controls, 7 males, 24 females	32 (29-42), median (quartiles)	Body mass: 65 (61-72.8) kg, median (quartiles) BMI: 22.9 (21.5 - 24.5) kg/m^2, median (quartiles)		Physical activity: Not reported		48 (40-55) mL/kg/min, median (quartiles)	
McQuade 1988 [33]	96 patients with CLBP: 50 males, 46 females	44.0 (9.7)	Not reported	79.2 (97.2) months	Disability: SIP: physical disability 4.9 (5.9), psychosocial disability 8.2 (8.3) Physical activity: Average standing and walking activity 5.7 (1.8) hours/day	A physical work capacity-150 test was used. A computer automatically provided resistance based on heart rate and guidelines for pedaling frequency. A work rate-heart rate ratio was calculated and subsequently standardized to an exercise heart rate level of 150.	Although no unit was specified, VO_{2max} results of 20.5 (6.6) seem to be reported in mL//kg/min	The unit in which oxygen uptake (aerobic capacity) was expressed is unknown, probably in mL/kg/min. In addition, it is unknown whether the reported oxygen uptake is an estimated (extrapolated) maximum aerobic capacity. Based on the rather low values this seems to be unlikely. No relevant conclusions for this study can be drawn.
	Controls: No control group							

Protas 2004 [34]	504 patients with CLBP: 341 males (67.7%), 163 females	40.1 (9.6)	Not reported	16.0 (27.1) months	Disability: VAS (0-100) 87.6 (23.8) Physical activity: Not reported	An incremental bicycle test was used. The initial work rate was 25 W and after 3 minutes work rate was increased by a heart rate dependent automatic response between 50 and 100 W (computerized calculation). In case the patient did not reach 85% of the maximum heart rate or did not stop the test for example because of fatigue, a similar calculation was performed after 3 minutes for the third and fourth stage. If at least two stages were ended due to fatigue with a heart rate ≥80 beats/min the test was valid. The test was always discontinued once the individual reached 85% of predicted maximum heart rate.	339 patients with CLBP with a valid test: 29.6 (10.7) mL/kg/min	Patients with CLBP had a similar aerobic capacity compared to patients with cervical disorders. No asymptomatic controls were included. However, 33% were unable to complete the exercise test. These patients were more often women, older, and of Hispanic ethnicity. Patients with an invalid score scored higher on disability score, pain intensity, and depressed mood compared to patients with a valid score. As no comparison was made with healthy controls, no relevant conclusions for this study can be drawn.
	Controls: No control group							
Rasmussen-Barr 2008 [35]	57 patients with CLBP: 29 males, 28 females	Total group 38 (11), males 39 (11), females 37 (11)	Body mass: total group 76 (16) kg, males 86 (10) kg, females 68 (16) kg BMI: total group 25 (4) kg/m^2; males: 26 (3) kg/m^2; females: 24 (5) kg/m^2	19 patients >8 weeks of current pain, 38 patients >12 weeks of current pain	Disability: ODI: total group 22 (ranging from 12 to 28), males 20 (ranging from 14 to 32), females 21 (ranging from 12 to 38) Physical activity patients with CLBP: Performing physical activities: patients with CLBP: 16% never, 23% once a month or less, 32% once per week, 30% more than once per week	The Åstrand test protocol. The test started with cycling at a work rate of 0.5 W/kg for 2 minutes. Work rate was then gradually increased to achieve a steady state heart rate of >120 beats/min.	Total group 35.8 (10.8) mL/kg/min, males 38.1 (10.6) mL/kg/min, females 33.6 (10.6) mL/kg/min	Patients with CLBP had a similar aerobic capacity as healthy controls. Female patients had a lower aerobic capacity than healthy female controls (p = 0.029). All patients (and controls) were able to complete the test according to the protocol. Although the authors discuss these values as normal, when comparing the control group with reference values of one large data set, aerobic capacity of the female control group scored in the good category, whereas the male control group scored in the poor/untrained category [65,67].

	Controls: 57 controls: 29 males, 28 females	Total group 38 (11), males 39 (11), females 37 (11)	Body mass: total group 73 (14) kg, males 83 (10) kg, females: 62 (8) kg BMI: total group 24 (4) kg/m^2, males 25 (3) kg/m^2, females 22 (3) kg/m^2		Physical activity controls: Performing physical activities: 5% never, 16% once a month or less, 57% once per week, 19% more than once per week		Total group 39.0 (9.0) mL/kg/min, males 38.2 (8.5) mL/kg/min, females 39.8 (9.7) mL/kg/min	
Robert 1995 [36]	30 patients with CLBP: 27 males, 3 females	31 (ranging from 20 to 59)	Body mass: males 82.7 kg, females 75.5 kg	Number of months off work: 9.3 (ranging from 1 to 30) months	Disability: Not reported Physical activity: Not reported	The YMCA submaximal cycle ergometer protocol. All patients completed the second and third work rates of the test. These two points were used to plot the slope of the line to estimate VO_{2max}.	30.5 mL/kg/min	Based on reference values published in an older edition of the book of Heyward (2nd edition, published in 1991), patients with CLBP were categorized as fair to average regarding their aerobic capacity [68]. However, when compared to a large dataset now also published in a more recent edition of the book of Heyward (7th edition, published in 2014), patients with CLBP in this study are categorized in the poor category [46]. All patients were able to complete the test according to the protocol. No other relevant conclusions were drawn.
	Controls: No control group							
Smeets 2009 [9]	223 patients with CLBP: 118 males, 105 females	Total group 42 (10.0), males 43 (9.1), females 40 (10.9)	Body mass: total group 81.0 (16.0) kg, males 88.0 (15.2) kg, females 74.0 (13.4) kg Lean body mass: total group 55.6 (11.2) kg, males 63.7 (8.2) kg, females 46.9 (6.3) kg	Total group 24 (12-72) months, median (first and third quartile), males 31 (14-84) months, median (first and third quartile), females 18 (11-60) months, median (first and third quartile)	Disability: RDQ: total group 13.8 (3.8), males 13.8 (3.9), females 13.9 (3.0) Physical activity: Baecke physical activity questionnaire: work: total group 2.4 (ranging from 0 to 3.3), males 2.3 (ranging from 0 to 3.3), females 2.6 (ranging from 0 to 3.4); leisure time (median and the first and third quartile): total group 2.8 (2.3-3.3), males 2.8 (2.3-3.3), females 2.8 (2.5-3.5); sport (median and the first and third quartile): total group 0 (0-1.7), males 0 (0-1.3), females 0 (0-1.7)	Modified submaximal Åstrand bicycle test. The modification was that the work rate was determined on lean body mass [30]. Patients started at a work rate of 0.5 W/kg lbm. After 2 minutes, work rate increased to 1.5 W/kg lbm. If the heart rate remained <120 beats/min, the work rate was increased by 0.5 W/kg lbm every 2 minutes. Once the heart rate was >120 beats/min, the patient cycled 6 minutes on a fixed work rate to reach steady state, meaning that heart rate did not vary more than ±5 beats/min during the final minute of exercise.	Total group 28.8 (7.2) mL/kg/min, 41.3 (9.1) mL/kg lbm/min, males 29.2 (7.8) mL/kg/min, 38.9 (8.8) mL/kg lbm/min, females 28.5 (6.5) mL/kg/min, 43.9 (8.8) mL/kg lbm/min	Patients with CLBP had a statistically significant lower aerobic capacity than age-, sex-, and physical activity-matched normative controls ($p < 0.001$) [65]. Male patients had a statistically significant lower aerobic capacity than female patients ($p < 0.001$). A total of 43 patients were not able to complete the test according to the protocol (19.3%). Main reasons premature test termination were pain and/or fatigue (n = 21), reaching their maximum heart rate (n = 6), too low pedaling frequency (n = 4). Patients that stopped the test because of pain/fatigue reported higher levels of pain and disability and had lower levels of aerobic fitness compared to participants who completed the test protocol. Five of the 180 patients who were able to complete the test used beta-blockers and were excluded.
	Controls: No control group							

Storheim 2000 [37]	29 patients with CLBP: 10 males, 19 females, randomized in 2 groups					The Åstrand test protocol, not specified.		No relevant conclusions can be drawn.
	Intervention group with CLBP: 5 males, 11 females	45.4 (11.1)	Body mass: 73.6 (14.4) kg Body height: 171.8 (10.8) cm	Not reported	Disability: ODI: intervention group with CLBP 20.9 (9.1) Physical activity: Physical activity during leisure time (on a 4-point scale, 0=inactive, 4=great activity): intervention group 0.81 (0.4) Heaviness of work load: n = 8 office work, n = 7 light manual handling, n = 1 heavy manual handling		37.4 (9.3) mL/kg/min	
	Control group with CLBP: 5 males, 8 females	48.3 (10.2)	Body mass: 70.0 (12.1) kg Body height: 173.0 (9.8) cm		Disability: ODI: control group with CLBP 17.0 (6.8) Physical activity: Physical activity during leisure time (on a 4-point scale, 0=inactive, 4=great activity): control group 1 (0.58) Heaviness of work load: n = 6 office work, n = 6 light manual handling, n = 1 heavy manual handling		37.5 (6.4) mL/kg/min	
	Controls: No control group							
Van der Velde 2000 [38]	258 patients with CLBP: 129 males, 129 females	34.2 (8.1)	Pooled data [16] BMI: 26.2 (5.6) kg/m^2	Not reported	Disability: ODI: 29.7 (95% CI: 26.7-32.1) Physical activity: Not reported	The Canadian aerobic fitness test. This is a multistage submaximal step test.	Only percentiles of patients with CLBP and controls against population norms of aerobic capacity were reported[69] Patients: mean percentile rank of 19.64 (95% CI: 17.5-21.8)	Aerobic capacity of patients with CLBP and controls both scored below the 1981 Canada fitness survey population norms (n = 13.258) [69]. It should be noted that controls were patients treated at the same facility for general fitness. This might explain their score below the population norm.
	Controls: 1001 controls, 415 males, 586 females	29.1 (10)	Controls: BMI not reported		Physical activity: Not reported		Controls: mean percentile rank of 35.58 (95% CI: 34.1-37.1)	

Verbunt 2003 [39]	37 patients with CLBP who were able to complete the test according to the protocol: 26 males, 11 females	Total group 45.2 (7.8), males 44.8 (6.9), females 46.1 (9.9)	Body mass: total group 82.0 (16.5) kg, males 86.3 (15.8) kg, females 71.7 (13.8) kg Body fat: total group 30.9 (8.5) %, males 27.7 (6.8) %, females 39.1 (6.8) %	Total group 11.7 (8.5) years, males 12.1 (8.6) years, females 10.9 (8.5) years	Disability: RDQ: total group 11.4 (5.4), males 9.9 (5.1), females 14.9 (4.5) Physical activity: 52% of the patients participated in sports activities on a regular basis, 26% participated in more than one sport activity	A modified Åstrand protocol according to the Siconolfi method. For males >35 years and for females of all ages, the initial work rate of 25 W was increased by 25 W every 2 minutes until a target heart rate was reached that was 70% of the predicted maximal heart rate (calculated as 220-age). For males <35, the initial work rate of 50 W was increased by 50 W every 2 minutes if the heart rate was less than 60% of the predicted maximum and by 25 W if it was between 60% and 70%. After attaining the target rate, all patients continued exercising at the same work rate for at least 2 additional minutes until steady state heart rate was reached. In the last 2 minutes, the range in heart rate had to be <5 beats/min for the test to end. If the variation was >5 beats, work rate was increased again until a steady state was reached.	Total group 2.43 (0.65) L/min, males 2.78 (0.49) L/min, females 1.60 (0.24) L/min Based on reported body mass and lean body mass, VO_{2max} corrected for body mass and lean body mass were calculated. Total group 29.6 mL/kg/min, 42.7 mL/kg lbm/min, males 32.2 mL/kg/min, 45.1 mL/kg lbm/min, females 22.3 mL/kg/min, 36.0 mL/kg lbm/min	Results were not compared with a control or reference group. However, based on the calculated VO_{2max} scores normalized for body mass and lean body mass, patients scored relatively low [65]. Three patients (7.5%) did not perform the exercise test according to the protocol due to knee complaints (n = 1), back pain (n = 1) and not being able to follow the test procedure (n = 1).
	Controls: No control group							
Wallbom 2002 [40]	50 patients with CLBP: 28 males, 22 females	42.5 (9.5)	Body mass: 83.3 (15.6) kg Body height: 172.0 (9.0) cm	52 (maximum of 384) months	Disability: QBPDS: 53.4 (15.9) Physical activity: Not reported	A submaximal bicycle test protocol. The initial work rate and resistance were based on the participant's heart rate, sex, and physical condition. This seems to be the YMCA submaximal cycle ergometer protocol.	Although no unit was specified, VO_{2max} results of 25.2 (10.0) seem to be reported in mL//kg/min	No relevant conclusions can be drawn.
	Controls: No control group							

Wittink 2000 [8]	50 patients with CLBP: 22 males, 28 females	Total group 39.8 (8.3), males 39.3 (6.1), females 40.1 (9.8)	Body mass: total group 78.3 (19.1) kg, males 84.4 (17.4) kg, females 73.5 (19.4) kg Body height: total group 170.0 (9.1) cm, males 176.2 (7.1) cm, females 165.2 (7.5) cm	Total group 40.2 (50) months, males 41.9 (59.8) months, females: 38.9 (41.9) months	Disability: Not reported Physical activity: Percentage that is not working: total group 54%, males 64%, females 46%, Percentage working full time: total group 20%, males 23%, females 18%	Modified Bruce protocol. The modification was a lower initial work rate and a less steep ramp, but not further specified. Patients were instructed to exercise as long as they could. A valid VO_{2max} was achieved when the participant met the following criteria: 1) an attained maximum heart rate >90% of predicted (220-age), 2) a plateau in oxygen uptake, or 3) a respiratory exchange ratio >1.00. In case this was not achieved VO_{2max} was extrapolated based on the submaximal test results (peak oxygen uptake and peak heart rate) to age predicted maximum heart rate.	Predicted VO_{2max}, total group 34.7 (10.6) mL/kg/min, males 39.3 (10.4) mL/kg/min, females: 30.9 (9.4) mL/kg/min	Aerobic capacity of patients with CLBP was similar to aerobic capacity of age-, sex-, and physical activity-matched controls [11,70]. Compared to this reference population, aerobic capacity of female patients with CLBP was relatively less affected compared to male patients, as VO_{2max} values of female patients corresponded to relatively active controls and the VO_{2max} values of male patients corresponded to sedentary controls. Reasons for ending the test were because of pain (50%), fatigue (42%), or test termination by reaching the determined maximum test criteria (8%). Males stopped more frequently because of pain than females.
	Controls: No control group							
Wormgoor 2008 [41]	Total group: 94 patients				Disability: Not reported Physical activity: Not reported	The Åstrand test protocol, with a work rate that resulted in a heart rate value between 120 and 170 beats/min after 6 minutes.	Males 29.7 mL/kg/min, females 27.8 mL/kg/min	On average, patients with specific and non-specific CLBP scored below age-, sex-, and body mass-specific normative controls ($p < 0.001$) [71]. Male patients with specific low back pain scored on average 72% of their predicted VO_{2max}, whereas female patients with specific low back pain scored on average 80% of their predicted VO_{2max}. Male patients with nonspecific low back pain scored on average 76% of their predicted VO_{2max}, whereas female patients with nonspecific low back pain scored on average 85% of their predicted VO_{2max}. In total, patients with CLBP seemed to have a mildly reduced aerobic capacity.
	19 patients with specific low back pain, 11 males, 8 females	43.3 (7.7)	Body mass: 77.1 (11.5) kg	Median of 24 months (interquartile range of 132 months)	Disability: ODI 33.4 (12.9) Physical activity: Sedentary 15.8%, light manual handling 15.8%, heavy manual handling: 68.5%		Males 28.4 mL/kg/min, females 26.0 mL/kg/min	
	55 patients with non-specific back pain, 29 males, 26 females	42 (9.7)	Body mass: 79.0 (15.7) kg	Median of 60 months (interquartile range of 185 months)	Disability: ODI: 25.3 (12.3) Physical activity: Sedentary 11.1%, light manual handling 20.4%, heavy manual handling: 68.6%		Males 30.7 mL/kg/min, females 26.5 mL/kg/min	

	22 patients with back pain as part of a widespread pain problem, 7 males, 13 females	40.1 (8.1)	Body mass: 69.5 (21.3) kg	Median of 41 months (inter-quartile range of 60 months)	Disability: ODI: 23.7 (12.9) Physical activity: Sedentary 10%, light manual handling 25.0%, heavy manual handling: 65.0%		Males 27.4 mL/kg/min, females 31.2 mL/kg/min	
	Controls: No (pain-free) control group							

Abbreviations: BMI= Body Mass Index; CI= Confidence Interval; CLBP = Chronic Low Back Pain; ODI= Oswestry Disability Index; QBPDS= Quebec Back Pain Disability Scale; RDQ= Roland Disability Questionnaire; SD= Standard Deviation; SIP = Sickness Impact Profile; VAS= Visual Analog Scale; VO_{2max}= Maximal Oxygen Uptake.

Table 3: Results of aerobic capacity measured with a submaximal exercise tests in patients with CLBP.

In five studies (29.4%), aerobic capacity of patients with CLBP was compared with normative data matched on age and sex [8,9,29,31,41]. Of these, two studies found a similar aerobic capacity in patients with CLBP compared to healthy controls, but both studies did not report the disability or physical activity level [8,31]. In the critical appraisal, the study of Hurri., *et al*. [31], scored 2/9 and Wittink., *et al*. [8], 4/9 items as low risk for bias. Three studies found a significantly lower aerobic capacity in patients with CLBP [9,29,41]. The study of Smeets., *et al*. [9], scoring 8/9 items as low risk for bias, included patients with a moderate disability level [47], and in the study of Wormgoor., *et al*. [41], scoring 3/9 items as low risk for bias, a moderately disabled nonspecific CLBP patient population was included [41,42]. In the study of Hodselmans., *et al*. [29], scoring 3/9 items as low risk for bias, the level of disability was not reported. In one study scoring 4/9 as low risk for bias, data of patients with CLBP were compared with an unclearly defined healthy population, probably matched for age and sex, and aerobic capacity of patients with CLBP was considered as fair-to-average [36,48]. In one study (5.9%) scoring 5/9 items as low risk for bias, aerobic capacity of patients with CLBP was compared with healthy controls that were not matched on age and sex. The main focus of that study was on psychometric properties and feasibility of a modified Åstrand test. It was found that the aerobic capacity of patients with CLBP was significantly lower [28]. In another study scoring 3/9 items as low risk for bias, patients were not compared to age- and sex-matched healthy controls [40]. In the study of van der Velde., *et al*. [38], scoring 1/9 item as low risk for bias, aerobic capacity prior to an intervention was compared with normative data, and it was concluded that the aerobic capacity of patients with CLBP was significantly lower [38]. In five studies (29.4%), data of patients with CLBP were not compared to a control group or normative data [30,33,34,37,39].

In seven studies (41.2%), information was provided about the number of patients completing the submaximal exercise test according to the protocol [8,9,28,34-36,39]. The percentage of patients who could not complete the test varied between 0% and 33%; these patients had higher levels of pain and disability compared to those who were able to complete the test. Four studies (23.5%) did not report the duration of the CLBP [27,30,37,38]. In the other thirteen studies, duration of complaints varied between a median score of 4.0 months [32] and a mean score of 79.2 months [33]. Three studies did not report the disability or physical activity level of the included population [31,32,36]. Regarding disability level, five studies used the Oswestry disability index [27,35,37,38,41], four studies used the Roland disability questionnaire [9,28,30,39], one study used the sickness impact profile [33], and one study used a visual analogue scale to score the disability level [34].

Interpretation of results of aerobic exercise testing in patients with CLBP

A summary of the findings and discussion of the methodology used of each study is presented in Table 4. In summary, 15 studies compared the aerobic capacity of patients with CLBP to age- and sex-matched controls or norm values. Five studies compared the aerobic capacity of patients with CLBP with the aerobic capacity of an age- and sex-matched control group. Of these five studies, three studies (60.0%) found a significantly lower aerobic capacity in patients with CLBP [10,22,32] and one study (20.0%) reported a significantly lower aerobic capacity in women, but not in men [35]. One study found a nearly statistically significant difference in aerobic capacity between patients with CLBP and age- and sex-matched healthy controls [27]. Regarding differences in included populations in these five studies, three studies used the Oswestry disability index to measure the level of disability. In two studies a relatively low score on the Oswestry disability index was reported (a mean score of 19 [22] and a median score of 22 [35]) indicating minimal-to-moderate disability, whereas the study of Brox., *et al*. [27] reported a high mean score of 43.5 indicating severe disability [43]. In ten studies, aerobic capacity of patients with CLBP was compared with norm values matched at least on age and sex [8,9,18-21,25,29,31,41]. Results of these studies are inconclusive. Five studies (50.0%) concluded that patients with CLBP had a lower aerobic capacity [9,18,20,29,41] and 5 studies (50.0%) found a similar aerobic capacity compared to age- and sex-matched norm values [8,19,21,25,31].

Name first author and year of publication	Conclusions
Atalay 2012 [17]	In this study, similar aerobic capacity in male and female patients with CLBP or in CLBP patients with radicular or non-radicular pain were found. Aerobic capacity was negatively associated with disc degeneration. No comparison was made with a pain-free control group and no comparison could be made with an appropriate set of norm values for aerobic capacity. To test aerobic capacity, a modified Bruce protocol was used. However, modifications were not specified. Although a maximal exercise test was performed, no criteria were used to control for poor performance increasing risk of systematic underestimation of some patients. The validity of testing equipment and calibration protocol were not reported. No overall score of all patients with CLBP was presented. For the purpose of this review, aerobic capacity data of subgroups, based on lumbar disc degeneration, were pooled [16]. Test results of this study should be interpreted with caution. The disability or physical activity level was not reported.

Bachynski-Cole 1985 [18]	Results of this study showed that the maximal work rate of patients with CLBP was 70% of mean maximal work rate of a control population in a cited study evaluating blood pressure response to exercise. A personalized graded maximal exercise test was used. To evaluate this with the control population, norm data were not matched for age. As only one patient stopped the test because of pain, patients with CLBP appeared to be capable to complete exercise testing. Although a maximal exercise test was performed, no information was given on how a maximal effort was distinguished from a submaximal performance due to early test termination, increasing systematic risk of underestimation. Test results of this study should be interpreted with caution. The disability or physical activity level was not reported.
Brox 2005 [27]	In this study, a nearly significant lower aerobic capacity (p = 0.06) was found in patients with CLBP compared to healthy age- and sex-matched controls. The exercise protocol was described inadequately. In this study, the well-known validated Åstrand submaximal exercise test was used, but the cited reference does not describe the protocol. In addition, it is unclear whether an age-correction was applied when calculating aerobic capacity from the nomogram.
Chan 2011 [19]	In this study, patients were randomized to evaluate the effect of two treatments. At baseline, a Bruce test was performed to measure aerobic capacity. According to age- and sex-adjusted standards, 43% and 48% of the participants were ranked below the 50^{th} percentile for VO_{2max}, indicating that >50% of the population in this study scored above the 50^{th} percentile of the norm population. Patients were compared against age-adjusted normative values from the Cooper institute [45]. Although a maximal exercise test was performed, there is a risk of systematic underestimation. No criteria were used to control whether indeed a maximum test performance was achieved. The exercise test protocol duration was likely to be longer than 12 minutes, increasing risk of poor performance in untrained subjects. The validity of testing equipment and a calibration protocol were not reported. Patients had a mean score of 30.8 and 28.8 on the Aberdeen low back pain disability scale (range 0-100).
Doury-Panchout 2012 [20]	In this study, aerobic capacity of patients with CLBP was compared with two other groups of patients with chronic pain syndromes (upper limb musculoskeletal disorder and multifocal chronic pain). No significant differences between the three patient groups were found. Compared to a reference group matched on age and sex, results of patients with CLBP corresponded with the physical condition category “very poor”. The exercise test was classified submaximal in case of patient exhaustion before the theoretical maximal heart rate was reached. However, no other criteria of a maximal effort were used to verify whether the performance was indeed submaximal. In addition, no extrapolation of this assumed submaximal aerobic capacity to a maximal aerobic capacity was performed. The test was classified as maximal in case theoretical maximal heart rate was reached, but test termination might have been prematurely. Therefore, there is a risk of systematic underestimation. The presented results were not reported separately for “submaximal” and “maximal” performers. In addition, the cited reference group was not tested with the same protocol. Therefore, the results of this study should be interpreted with caution.
Duque 2009 [21]	According to the authors, aerobic capacity of patients with CLBP was similar compared to aerobic capacity of a healthy, but poorly conditioned reference group matched on age and sex; however, the cited norm values are old and unclear. The decline of VO_{2max} with increasing age was in male patients with CLBP lower than in healthy and active subjects. Patients performed a maximal cardiopulmonary exercise test, after which it was verified whether patients performed a maximal effort. This control for maximal effort was performed with well-described secondary objective criteria. Patients, who did not perform a maximal effort (31%) did not differ significantly from patients who performed a maximal effort concerning anthropometric parameters, severity of back pain, and level of disability. Patients who did not perform a valid maximal cardiopulmonary exercise test were not included in the analysis.
Duque 2011 [10]	Results of this study showed that patients with CLBP had a lower aerobic capacity compared to a healthy asymptomatic age- and sex-matched control group. The patients reported in this study were the same patients as mentioned in the 2009 study [21]. Both absolute and relative (normalized for body mass) VO_{2max} values were lower in patients compared to controls. Both male and female patients scored lower compared to controls. Male patients with CLBP had a higher activity at work compared to females, which was assumed to explain this difference.
Hoch 2006 [22]	In this study, a lower aerobic capacity was found in the CLBP group compared to healthy controls (both only female) matched on age. However, the healthy control group had a relatively high aerobic capacity (75^{th} percentile of norm values) and the CLBP group scored at the 50^{th} percentile. CLBP patients and controls were highly educated and both highly active. Patients with CLBP had relatively low disability levels. Aerobic capacity was measured with a maximal treadmill exercise test. No criteria to control for poor performance were used, increasing the risk of systematic underestimation; therefore, results should be interpreted with caution.
Hodselmans 2001 [30]	This study was an intervention study that randomized patients in a control (waiting list) or intervention group, and no conclusion on aerobic capacity of patients with CLBP was made. The control group was younger than the intervention group. Aerobic capacity was measured using a submaximal lean body mass-based Åstrand test (reported to be valid in the study of Hodselmans., *et al.* [28]).
Hodselmans 2008 [28]	The aim of this study was to investigate reliability, validity, and feasibility of the submaximal lean body mass-based Åstrand test. The control group was recruited from the student population of the University of Groningen, the Netherlands, and was therefore not comparable with the group of patients with CLBP. However, aerobic capacity of patients with CLBP was lower compared to the control group. Aerobic capacity was measured using a submaximal exercise test. No relevant conclusions on aerobic capacity in patients with CLBP were made, as this was not the aim of the study.
Hodselmans 2010 [29]	Patients with nonspecific CLBP had a significantly reduced level of aerobic capacity compared to an age-, sex-, and physical activity-matched Dutch reference population. Aerobic capacity was measured using the valid and reliable submaximal lean body mass-based Åstrand test.
Hurri 1991 [31]	The authors reported a similar aerobic capacity between patients with CLBP and a healthy reference population matched on age and sex. Aerobic capacity from participants was estimated with a test protocol with questionable psychometric properties, after which estimated data were compared with a relatively old set of reference values collected in participants from another country.
Kell 2009[23]	The aim of this study was to compare two treatments in patients with CLBP. Therefore, no comparison was made with a reference group or healthy control group, and no relevant conclusions on aerobic capacity of patients with CLBP compared to healthy controls were made. Aerobic capacity was measured with a maximal exercise test.
Keller 2001 [32]	In this study, patients with CLBP performed worse than controls on a submaximal exercise test (Åstrand test). Although aerobic capacity was significantly higher in the healthy subjects, the reported aerobic capacity of patients with CLBP in the current study (median of 36 mL/kg/min, interquartile range 32-46) seem within the normal range when compared to larger reference sets [65].

Koldas Dogan 2008 [24]	The study aim was to investigate the effects of three therapeutic approaches for patients with CLBP. One outcome of interest was aerobic capacity. However, no control group was included and therefore no relevant conclusions for this review can be made. Aerobic capacity was measured using a maximal treadmill test without controlling for maximal performance, increasing risk of underestimation caused by test termination before reaching objective maximal aerobic capacity. The test protocol was not clearly described, making it unclear if this was in accordance with the regular test protocol. The values for aerobic capacity were described as oxygen uptake in mL/kg/min. However, values seem to be in L/min, which could not be re-calculated because body mass values were not provided (not in manuscript and also not after requesting the authors).
McQuade 1988 [33]	The main aim of this study was to describe the association between physical fitness and important aspects of CLBP. The authors tested aerobic capacity with a submaximal exercise test (PWC-150). However, unit of oxygen uptake was not specified and it seems that values were not extrapolated to maximum aerobic capacity. No comparison with controls or reference data was made.
Protas 2004 [34]	This study evaluated whether patients with CLBP and chronic cervical spine disorders differ in pre- and post-rehabilitation aerobic capacity. Patients with CLBP had similar levels of aerobic capacity compared to patients with chronic cervical disorders. However, a large number (33%) of patients with CLBP did not complete the submaximal exercise test before intervention. Therefore, it is questionable whether the chosen test is useful for patients with CLBP. Patients were not compared against a healthy reference group matched on age and sex. Although not clearly described, it appears that patients were tested according to the validated YMCA submaximal cycle ergometer protocol. When reported aerobic capacity values are compared to large reference sets on aerobic capacity, CLBP patients scored in the poor-to-fair category [45].
Rasmussen-Barr 2008 [35]	A similar predicted aerobic capacity was found in patients with CLBP and age- and sex-matched healthy controls, measured with a submaximal exercise test (Åstrand test). Female patients with CLBP had lower levels of aerobic capacity compared to female controls. However, aerobic capacity of healthy female controls was relatively high compared to large datasets, whereas male patients with CLBP had a similar score, as the control group was categorized as untrained or having a poor aerobic capacity [65,67].
Robert 1995 [36]	The goal of the study was to investigate the effect of a work hardening program. Patients were tested with a submaximal exercise test (YMCA submaximal cycle ergometer protocol). Patients with CLBP had a fair-to-average aerobic capacity when compared to reference data published in 1991 [68]. However, when compared to a more recent dataset published in a new edition of the book of Heyward., *et al*. patients would be categorized as poor [46,67].
Smeets 2009 [9]	Results of this study showed that most patients with CLBP-associated disability had a lower level of aerobic capacity compared to a reference group matched on age, sex, and level of sports activity. Patients were measured using a submaximal exercise test (modified Åstrand test). Aerobic capacity was reported relative to body mass and relative to lean body mass.
Storheim 2000 [37]	The aim of this study was to evaluate the difference in effect of a training intervention between two groups of patients with CLBP. No comparison was made against healthy controls. Aerobic capacity was measured using a submaximal exercise test (Åstrand test). For the purpose of this review no relevant conclusions were made.
Van der Velde 2000 [38]	Both patients and controls had a lower aerobic capacity compared to Canadian population norms from 1981. Aerobic capacity was only compared with the population norm and not with the control group. Absolute VO_{2max} values were not reported. Only percentiles against the population norm were reported, which limits interpretation and generalizability of the results. However, patients with CLBP scored at the 19.6 percentile (95% CI: 17.5-21.8) of a representative sample of the Canadian population.
Verbrugghe 2019 [26]	This study aimed to compare the effects of a high-intensity exercise therapy program with a similar moderate-intensity exercise therapy program on disability, pain, function, aerobic capacity, and abdominal and back muscle strength in patients with CLBP, in which no comparison was made with healthy controls. Aerobic capacity was assessed using maximal cardiopulmonary exercise testing on a cycle ergometer. As a group, patients would be classified in the poor-to-fair category for aerobic capacity compared to sex- and age-matched norm values [46].
Verbrugghe 2020 [25]	The authors investigated to which extent disability, psychological and pain-related factors were associated with the outcomes of abdominal and back muscle strength test and aerobic capacity (assessed using cardiopulmonary exercise testing on a cycle ergometer) in patients with CLBP. Patients would be classified in the poor-to-fair category compared to sex- and age-matched norm values for aerobic capacity [46] Based on the Oswestry disability index, patients scored rather low regarding their disability level [43].
Verbunt 2003 [39]	The goal of this study was to test the assumption that fear of injury leads to disability and physical deconditioning in patients with CLBP, and to evaluate the relation between disability and physical deconditioning. In this study, no comparison was made with healthy controls or a reference population. For the purpose of this review the reported absolute VO_{2max} values were also normalized for body mass and lean body mass and compared with the norm population of Vos [65]. It can be concluded that males and females with CLBP scored lower than the norm population. Exercise testing was performed using a validated submaximal exercise test (Siconolfi test).
Wallbom 2002 [40]	The purpose of the study of Wallbom was to examine the correlation between cardiovascular performance, psychosocial factors, and perceived exertion among persons with chronic pain. Patients seem to score rather low compared to norm values [67].
Wittink 2000 [8]	According to the authors, the aerobic capacity of patients with CLBP was similar to the aerobic capacity of age-, sex-, and physical activity-matched controls. VO_{2max} of females with CLBP corresponded to active controls, whereas the VO_{2max} of males with CLBP corresponded to sedentary controls. Although a maximal exercise test should have been performed, extrapolation from submaximal performance was done in case predetermined VO_{2max} criteria were not met.
Wormgoor 2008 [41]	Results of this study showed that patients with CLBP have mildly reduced values for aerobic capacity compared to normative data matched on age, sex, and body mass. Males were more affected than females. Exercise testing was performed using the Åstrand test.
Abbreviations: CI= Confidence Interval; CLBP: Chronic Low Back Pain; VO_{2max}= Maximal Oxygen Uptake.	

Table 4: Interpretation of study results regarding aerobic capacity in patients with CLBP.

Discussion

The main aim of this systematic review was to critically appraise the different methodologies used to evaluate the aerobic capacity of patients with CLBP, as well as to unravel whether patients with CLBP have a lower aerobic capacity compared to age- and sex-matched healthy subjects. The main findings were that large differences exist in the risk of confounding and bias of the protocols and methodologies used in the included studies. Many different exercise test protocols and methodologies were used, and details of included populations were not systematically specified regarding the level of disability, physical activity, and duration of pain complaints. Without taking the above-mentioned issues into account, most studies found a lower aerobic capacity in patients with CLBP compared to age- and sex-matched healthy controls.

Based on the finding that most studies found a lower aerobic capacity in patients with CLBP compared to age- and sex-matched healthy controls, one might conclude that patients with CLBP are deconditioned. However, there are several points that warrant cautiousness regarding this conclusion. First, of the 28 included studies in this review using exercise tests to objectively measure or estimate aerobic capacity of patients with CLBP, 15 studies compared the aerobic capacity of patients with CLBP with an age- and sex-matched control group or norm values. Of these 15 studies, seven studies used a maximal cardiopulmonary exercise test [10,18-22,25]. Four of these seven studies clearly concluded that patients with CLBP have a lower aerobic capacity compared to controls [10,18,20,22]. Maximal cardiopulmonary exercise testing is considered the gold standard to assess aerobic capacity (VO_{2max}) [7]. A clear plateau in oxygen uptake despite an increase in work rate at the end of the test is required to speak of a true VO_{2max}. When a patient demonstrates no true VO_{2max}, the oxygen uptake during the last 30 seconds of the test (VO_{2peak}) can be confirmed to be interchangeable with VO_{2max} by completing a supramaximal verification protocol following the cardiopulmonary exercise test. However, performing a supramaximal exercise test is often not feasible in clinical populations; therefore, a valid interpretation of a maximal cardiopulmonary exercise test should minimally use secondary objective criteria to verify whether or not the exercise test was performed maximally. These secondary objective criteria might include a respiratory exchange ratio at peak exercise >1.10 or a heart rate at peak exercise >95% of the age-predicted maximal heart rate. In all included studies in this review using a maximal cardiopulmonary exercise test, achieved VO_{2peak} or VO_{2max} values were not verified by a supramaximal exercise test in those subjects that did not show a clear VO_2 plateau at the end of the test. Only four studies [10,21,23,26] used appropriate secondary objective criteria to verify the attained VO_{2peak} or VO_{2max} values, whereas the other seven studies executed the test without controlling whether participants delivered a maximal effort [17-20,22,24,25]. Thus, although four of the seven studies found a lower aerobic capacity of patients with CLBP compared to an age- and sex-matched control group or norm values, it is unclear whether the reported VO_{2peak} or VO_{2max} values are 'true' VO_{2max} values that are required to draw a valid conclusion. The criteria used to discriminate between good and poor effort may depend on exercise modality and the aerobic capacity may be reduced in exercise tests of long duration and large increments [49,50]. The most optimal duration of the maximal cardiopulmonary exercise test protocol (excluding warm-up and cool-down) is between 8 and 12 minutes, and work rate increments should be chosen carefully for each individual participant (e.g., taking sex, body mass, and physical fitness into account) [51,52]. In the included studies, it is questionable whether the applied increases in work rate resulted in this optimal test duration. An alternative for maximal cardiopulmonary exercise testing to measure the patient's aerobic capacity is submaximal exercise testing. Despite the fact that indirect tests are more accessible and more easily implemented in clinical practice, they rely on assumptions, such as a linear relation between heart rate and oxygen consumption, a predicted maximal heart rate with a standard deviation of about 10 beats/min, and/or a constant mechanical efficiency [53]. These assumptions are potential sources of error in predicting aerobic capacity. For example, Akalan., *et al*. [54] found that the mean difference between the estimated VO_{2max} from submaximal exercise tests (YMCA, ACSM, and Åstrand cycle ergometer test) was significantly lower than the observed VO_{2max} during maximal cardiopulmonary exercise testing. Moreover, predictions of VO_{2max} based on submaximal exercise tests might be adequate at group level, but they are insufficiently accurate in individual patients [13,55]. Submaximal exercise tests like the Åstrand test are often used as a less-sophisticated alternative for estimating aerobic capacity in patients with CLBP. However, the validity and reliability was found to be poor or unclear [13,54]. Overall, validity and test-retest reproducibility of the used test protocol was poor or not mentioned in the included studies. In eight of the 28 included studies a submaximal aerobic exercise test was performed and predicted aerobic capacity of patients with CLBP was compared with an age- and sex-matched control group or norm values [8,9,27,29,31,32,35,41]. Four studies concluded that patients with CLBP had a lower aerobic capacity compared to age- and sex-matched healthy controls [9,29,32,41], and one study concluded that only female patients had a lower aerobic capacity [35].

Second, a subgroup of patients with CLBP was not able to complete a maximal exercise test according to the protocol. Regarding maximal cardiopulmonary exercise testing, five of the eleven studies reported the percentage of patients that appeared to be unable to perform the test maximally, which varied between 0 and 58% [10,18,20,21,25]. Patients who were not able and those who were able to complete the test did not differ on the level of pain and disability [10,21]. Remarkably, all patients in the study of Verbrugghe., *et al*. [25] were able to perform a valid maximal effort; however, these patients had a relatively low disability level. In a recent study and therefore not included in this review, 91.9% of the patients with CLBP with a median score on disability were able to complete a maximal cardiopulmonary exercise test [56]. In case a patient is either unwilling or unable to deliver a maximal effort, the use of submaximal parameters derived from maximal cardiopulmonary exercise testing seem essential to still be able to gain insight in this patient's aerobic capacity. The ventilatory anaerobic threshold and the oxygen uptake efficiency slope might be useful and robust submaximal indicators of a patient's aerobic capacity, as these parameters correlate well with VO_{2max} in several patient populations [57-59]. Especially the ventilatory anaerobic threshold might be a useful measure, as work below this level encompass most daily life activities. Future studies should assess the validity of submaximal indicators of aerobic capacity in patients with CLBP, as well as compare their values with age- and sex-matched healthy controls. Regarding submaximal exercise testing, seven of the seventeen studies provided information on dropouts [8,9,28,34-36,39]. The percentage varied between 0% and 33%. The patients who stopped the test prematurely scored higher on disability and pain intensity and lower on sports activity level compared to patients who completed the test [9,34]. As aerobic capacity of patients who were not able to complete the exercise test were not available, these missing data could have biased the final results and interpretation. Based on this, it should be considered that is unclear whether the used exercise test protocol and/or outcome measures resulted in a selective dropout and this may have influenced the results of the study.

Third, patients who are more disabled in daily physical functioning are assumed to have a lower aerobic capacity [5]. To demonstrate whether this is actually the case, the disability or physical activity level of the patient population needs to be reported. However, in seven of the 28 included studies the disability or physical activity level was not reported. If reported, diverse measurement instruments were used, making interpretation of the characteristics of the included populations challenging. Furthermore, aerobic capacity as a characteristic of deconditioning is thought to be lower in patients with longer duration of CLBP. However, 6 of the 26 included studies did not report the duration of CLBP [18,22,27,30,37,38]. In the study of Brox., *et al*. [27], the estimated aerobic capacity of patients with chronic and subacute low back pain and healthy controls were compared using submaximal exercise testing. Results showed that the aerobic capacity of patients with subacute low back pain was lower than healthy controls, but the aerobic capacity of patients with CLBP was not significantly different compared to healthy controls. For patients with subacute low back pain, it is questionable whether this is indeed a sign of physical deconditioning or whether a patient's behavior during testing is measured [60]. Maximal aerobic capacity measurement might be limited by a patient's behavior, resulting in a less adequate estimation of aerobic capacity. In the fear avoidance model, psychological factors as pain catastrophizing and fear of movement are assumed to influence the patient's daily life activities and in the long run result in deconditioning. However, no association has been found between aerobic capacity and pain catastrophizing or fear of movement in patients with CLBP [39,61]. However, when measuring a patient's aerobic capacity, one would assume to measure the actual aerobic capacity and not the patient's behavior during aerobic capacity testing. This emphasizes the importance of verifying whether the patient adhered to the (sub)maximal exercise test protocol and performed a true maximal effort when performing maximal cardiopulmonary exercise testing, which is the preferred methodology. One can then also evaluate effort-independent indicators of aerobic capacity (ventilatory anaerobic threshold and the oxygen uptake efficiency slope). Furthermore, it is recommendable to describe the disability, physical activity level, and duration of complaints of patients.

Fourth, regarding the use of an age- and sex-matched control group or the use of normative data to evaluate the aerobic capacity of patients with CLBP, it can be argued that the use of a proper normative dataset collected using the same (sub) maximal aerobic test and protocol is preferable over the use of a control group. When including a healthy control group there might be a risk of selection bias [44]. In case of a large recently collected normative data set, the population can be divided in categories ranging from sedentary to highly trained persons. Furthermore, different aspects like ethnicity, smoking habits, and physical activity can be included as potential confounders. A nice illustration of this point is made by the studies of Duque., *et al*. [10,21]. These two studies were based on the same group of patients with CLBP. However, in one study the patients were merely compared with a normative data set [21], whereas patients in the other study were compared with a healthy control group and normative data [10]. This has led to different conclusions of the aerobic capacity of patients with CLBP.

Study limitations

Several studies included and discussed in this review were not designed to evaluate whether patients with CLBP have a lower aerobic capacity than healthy subjects (e.g. study on effectiveness of treatment of which only baseline data were used for our review). Therefore, some for the critical appraisal relevant items might not have been elaborated in the methods, as these were not relevant for the aim of that particular study. We still decided to include these studies to give a complete overview and discussion of methods used in the field of CLBP research. Due to the heterogeneity of the used exercise protocols and methodologies, and since no study included in this review scored low risk for confounding and bias on the critical appraisal, a meta-analysis was not performed.

Conclusion

It remains unclear whether deconditioning is present in patients with CLBP, as there are several points that warrant cautiousness before drawing a definitive conclusion. It is recommended to use a maximal cardiopulmonary exercise test with an adequate assessment of the patient's effort when using aerobic capacity testing in clinical practice. If a patient did not perform a maximal effort, submaximal indicators of aerobic capacity might be useful. In case submaximal exercise testing is applied, protocol validity and test-retest reproducibility should be adequate and adherence of the patient should be critically evaluated. One should be aware that utilizing submaximal exercise testing might result in a substantial under or overestimation of aerobic capacity in individual patients. Finally, it remains unclear whether patients with CLBP are indeed deconditioned. This should be evaluated in further studies before aerobic capacity testing can be used to decide whether reconditioning of patients is necessary or only treatments aimed at changing behavioral factors are sufficient.

Acknowledgements

None.

Declaration of Interest Statement

None.

Bibliography

1. Verbunt JA., *et al.* "Cause or effect? Deconditioning and chronic low back pain". *Pain* 149.3 (2010): 428-430.

2. Hayden JA., *et al.* "Exercise therapy for treatment of non-specific low back pain". *Cochrane Database of Systematic Reviews* 3 (2005): CD000335.

3. Wun A., *et al.* "Why is exercise prescribed for people with chronic low back pain? A review of the mechanisms of benefit proposed by clinical trialists". *Musculoskeletal Science and Practice* 51 (2021): 102307.

4. Vlaeyen JW., *et al.* "Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance". *Pain* 62.3 (1995): 363-372.

5. Verbunt JA., *et al.* "Disuse and deconditioning in chronic low back pain: concepts and hypotheses on contributing mechanisms". *European Journal of Pain* 7.1 (2003): 9-21.

6. Smeets RJ., *et al.* "The association of physical deconditioning and chronic low back pain: a hypothesis-oriented systematic review". *Disability and Rehabilitation* 28.11 (2006): 673-693.

7. Shephard RJ., *et al.* "The maximum oxygen intake. An international reference standard of cardiorespiratory fitness". *Bulletin of the World Health Organization* 38.5 (1968): 757-764.

8. Wittink H., *et al.* "Deconditioning in patients with chronic low back pain-Fact or fiction?" *Spine* 25.17 (2000): 2221-2228.

9. Smeets RJ., *et al.* "Is the Fear Avoidance Model Associated with the Reduced Level of Aerobic Fitness in Patients with Chronic Low Back Pain?" *Archives of Physical Medicine and Rehabilitation* 90.1 (2009): 109-117.

10. Duque I., *et al.* "Maximal aerobic power in patients with chronic low back pain: A comparison with healthy subjects". *European Spine Journal* 20.1 (2011): 87-93.

11. Astrand I. "Aerobic work capacity in men and women with special reference to age". *Acta physiologica Scandinavica. Supplementum* 49.169 (1960): 1-92.

12. Astrand PO., *et al.* "Evaluation of physical performance based on tests, in Textbook of work physiology". Human Kinetics: Champaign (2003): 273-297.

13. Gibbons RJ., *et al.* "ACC/AHA guidelines for exercise testing: executive summary. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing)". *Circulation* 96.1 (1997): 345-354.

14. Higgins JPT and S Green. "Cochrane handbook for systematic reviews of interventions". John Wiley and Sons Ltd: Chichester (2009): 187-235.

15. Sanderson S., *et al.* "Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: a systematic review and annotated bibliography". *International Journal of Epidemiology* 36.3 (2007): 666-676.

16. Arsham H. "Pooling the means, and variances".

17. Atalay A., *et al.* "Deconditioning in chronic low back pain: Might there be a relationship between fitness and magnetic resonance imaging findings?" *Rheumatology International* 32.1 (2012): 21-25.

18. Bachynski-Cole., *et al.* "The cardiovascular fitness of disabled patients attending occupational therapy". *Occupational Therapy Journal of Research* 5.4 (1985): 233-242.

19. Chan CW., *et al.* "Aerobic exercise training in addition to conventional physiotherapy for chronic low back pain: a randomized controlled trial". *Archives of Physical Medicine and Rehabilitation* 92 (2011): 1681-1685.

20. Doury-Panchout F., *et al.* "VO2max in patients with chronic pain: Comparative analysis with objective and subjective tests of disability". *Annals of Physical and Rehabilitation Medicine* 55.5 (2012): 294-311.

21. Duque I., *et al.* "Physical deconditioning in chronic low back pain". *Journal of rehabilitation medicine*. Official Journal of the UEMS European Board of Physical and Rehabilitation Medicine 41.4 (2009): 262-266.

22. Hoch AZ., *et al.* "Aerobic fitness in women with chronic discogenic non radicular low back pain". *American Journal of Physical Medicine and Rehabilitation* 85.7 (2006): 607-613.

23. Kell RT and GJG Asmundson. "A comparison of two forms of periodized exercise rehabilitation programs in the management of chronic nonspecific low-back pain". *Journal of Strength and Conditioning Research* 23.2 (2009): 513-523.

24. Koldas Dogan S., *et al.* "Comparison of three different approaches in the treatment of chronic low back pain". *Clinical Rheumatology* 27.7 (2008): 873-881.

25. Verbrugghe J., *et al.* "Disability, kinesiophobia, perceived stress, and pain are not associated with trunk muscle strength or aerobic capacity in chronic nonspecific low back pain". *Physical Therapy in Sport* 43 (2020): 77-83.

26. Verbrugghe J., *et al.* "Exercise Intensity Matters in Chronic Nonspecific Low Back Pain Rehabilitation". *Medicine and Science in Sports and Exercise* 51.12 (2019): 2434-2442.

27. Brox JI., *et al.* "Disability, pain, psychological factors and physical performance in healthy controls, patients with sub-acute and chronic low back pain: a case-control study". *Journal of Rehabilitation Medicine* 37.2 (2005): 95-99.

28. Hodselmans AP., *et al.* "Exercise capacity in non-specific chronic low back pain patients: A lean body mass-based Astrand bicycle test; reliability, validity and feasibility". *Journal of Occupational Rehabilitation* 18.3 (2008): 282-289.

29. Hodselmans AP., *et al.* "Nonspecific chronic low back pain patients are deconditioned and have an increased body fat percentage". *International Journal of Rehabilitation Research* 33.3 (2010): 268-270.

30. Hodselmans AP., *et al.* "Short-term outcomes of a back school program for chronic low back pain". *Archives of Physical Medicine and Rehabilitation* 82.8 (2001): 1099-1105.

31. Hurri H., *et al.* "Aerobic capacity among chronic low-back-pain patients". *Journal of Spinal Disorders* 4.1 (1991): 34-38.

32. Keller A., *et al.* "Reliability of the Isokinetic Trunk Extensor Test, Biering-Sorensen Test, and Astrand bicycle test-Assessment of intraclass correlation coefficient and critical difference in patients with chronic low back pain and healthy individuals". *Spine* 26.7 (2001): 771-777.

33. McQuade KJ., *et al.* "Physical fitness and chronic low back pain. An analysis of the relationships among fitness, functional limitations, and depression". *Clinical Orthopaedics and Related Research* 233 (1988): 198-204.

34. Protas EJ., *et al.* "Relevance of aerobic capacity measurements in the treatment of chronic work-related spinal disorders". *Spine* 29.19 (2004): 2158-2166.

35. Rasmussen-Barr E., *et al.* "Aerobic fitness in patients at work despite recurrent low back pain: a cross-sectional study with healthy age- and gender-matched controls". *Journal of Rehabilitation Medicine* 40.5 (2008): 359-365.

36. Robert JJ., *et al.* "The effects of a work hardening program on cardiovascular fitness and muscular strength". *Spine* 20.10 (1995): 1187-1193.

37. Storheim K and K Bo. "The effect of intensive group exercise in patients with chronic low back pain". *Advances in Physiotherapy* 2 (2000): 113-123.

38. Velde G and D Mierau "The effect of exercise on percentile rank aerobic capacity, pain, and self-rated disability in patients with chronic low-back pain: a retrospective chart review". *Archives of Physical Medicine and Rehabilitation* 81 (2000): 1457-1463.

39. Verbunt JA., *et al.* "Fear of injury and physical deconditioning in patients with chronic low back pain". *Archives of Physical Medicine and Rehabilitation* 84.8 (2003): 1227-1232.

40. Wallbom AS., *et al.* "Concordance between rating of perceived exertion and function in persons with chronic, disabling back pain". *Journal of Occupational Rehabilitation* 12.2 (2002): 93-98.

41. Wormgoor ME., *et al.* "The impact of aerobic fitness on functioning in chronic back pain". *European Spine Journal* 17.4 (2008): 475-483.

42. Ramasamy A., *et al.* "Assessment of Patient-Reported Outcome Instruments to Assess Chronic Low Back Pain". *Pain Medicine* 18.6 (2017): 1098-1110.

43. Vianin M. "Psychometric properties and clinical usefulness of the Oswestry Disability Index". *Journal of Chiropractic Medicine* 7.4 (2008): 161-163.

44. ATS and ACCP. "ATS/ACCP statement on cardiopulmonary exercise testing". *American Journal of Respiratory and Critical Care Medicine* 167.2 (2003): 211-277.

45. "ACSM's guidelines for exercise testing and prescription 8th edition". A.C.o.S. Medicine. Philadelphia: Lippincott Williams and Wilkins (2009).

46. Heyward V. "Advanced Fitness Assessment and Exercise Prescription". *Human Kinetics* Champain, IL (2014).

47. Nicholas MK., *et al.* "What do the numbers mean? Normative data in chronic pain measures". *Pain* 134.1-2 (2008): 158-173.

48. The Cooper Institute, Physical fitness assessments and norms (2002): 36-38..

49. Midgley AW., *et al.* "Evaluation of true maximal oxygen uptake based on a novel set of standardized criteria". *Applied Physiology, Nutrition, and Metabolism* 34.2 (2009): 115-123.

50. Roffey DM., *et al.* "Effect of stage duration on physiological variables commonly used to determine maximum aerobic performance during cycle ergometry". *Journal of Sports Science* 25.12 (2007): 1325-1335.

51. Balady GJ., *et al.* "Clinician's Guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association". *Circulation* 122.2 (2010): 191-225.

52. Pescatello L., *et al.* "ACSM's guidelines for exercise testing and prescription". 9th edition. ed. L. Pescatello. Philadelphia: Lippincot Williams and Wilkins (2013): 40-156.

53. McArdle WD., *et al.* "Exercise physiology: energy, nutrition, and human performance". (8th edition). Philadelphia: Wolters Kluwer Health | Lippincott Williams and Wilkins (2015).

54. Akalan C., *et al.* "Prediction of VO2max from an individualized submaximal cycle ergometer protocol". *Journal of Exercise Physiology* 2008. 11.2 (2008): 1-17.

55. Stuiver MM., *et al.* "Validation and Refinement of Prediction Models to Estimate Exercise Capacity in Cancer Survivors Using the Steep Ramp Test". *Archives of Physical Medicine and Rehabilitation* 98.11 (2017): 2167-2173.

56. Ansuategui Echeita J., *et al.* "Maximal cardiopulmonary exercise test in patients with chronic low back pain: feasibility, tolerance and relation with central sensitization. An observational study". *Disability and Rehabilitation* (2021): 1-8.

57. Baba R., *et al.* "Oxygen uptake efficiency slope: a new index of cardiorespiratory functional reserve derived from the relation between oxygen uptake and minute ventilation during incremental exercise". *Journal of the American College of Cardiology* 28.6 (1996): 1567-1572.

58. Bongers BC., *et al.* "An evaluation of the validity of the pre-operative oxygen uptake efficiency slope as an indicator of cardiorespiratory fitness in elderly patients scheduled for major colorectal surgery". *Anaesthesia* 72.10 (2017): 1206-1216.

59. Pogliaghi S., *et al.* "Calculation of oxygen uptake efficiency slope based on heart rate reserve end-points in healthy elderly subjects". *European Journal of Applied Physiology* 101.6 (2007): 691-696.

60. Huijnen IP., *et al.* "Physical performance measurement in chronic low back pain: measuring physical capacity or pain-related behaviour?" *European Journal of Physics* (2013): 103-110.

61. Smeets RJ., *et al.* "Do patients with chronic low back pain have a lower level of aerobic fitness than healthy controls? are pain, disability, fear of injury, working status, or level of leisure time activity associated with the difference in aerobic fitness level?" *Spine* (Phila Pa 1976) 31.1 (2006): 90-97.

62. Erikssen., *et al.* "Blood pressure responses to bicycleexercise testing in apparently healthy middle-aged men". *Cardiology* 66 (1980): 56-63.

63. Shvartz E and RC Reibold. "Aerobic fitness norms for males and females aged 6 to 75 years: a review". *Aviation, Space, and Environmental Medicine* 61 (1990): 3-11.

64. Astrand PO. "Quantification of exercise capability and evaluation of physical capacity in man". *Progress in Cardiovascular Diseases* 19.1 (1976): 51-67.

65. Vos JA. "Ergometry and exercise accompaniment". Amersfoort: Nederland's Paramedisch Instituut (2004).

66. Seliger V and Z Bartunek. "Mean Values of Indices of Physical Fitness in the Investigation of Czechoslovak Population Aged 12-55 Years". Prague, Czechoslovakia: Czechoslovak Association of Physical Culture (1976).

67. Research CIFA. "The fitness specialist certification manual" (2005).

68. Heyward V. "Advanced Fitness Assessment and Exercise Prescription". *Human Kinetics.* Champain, IL (1991).

69. Government of Canada, M.O.S., Fitness and Amateur Sport. "Canadian Standardized Test of Fitness (CSTF) operations manual". Government of Canada: Ottawa (1987).

70. Fletcher GF., *et al.* "Statement on exercise: benefits and recommendations for physical activity programs for all Americans. A statement for health professionals by the Committee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association". *Circulation* 94.4 (1996): 857-862.

71. Fletcher GF., *et al.* "Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association". *Circulation* 104.14 (2001): 1694-740.