REVIEW

Can combined aerobic and muscle strength training improve aerobic fitness, muscle strength, function and quality of life in people with spinal cord injury? A systematic review

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Study design: A systematic review.

Objectives: The aim of this systematic review was to establish whether combined aerobic training and muscle strength training is effective in improving aerobic fitness, muscle strength, function and/or quality of life (QoL) in people with spinal cord injury (SCI).

Settings: Faculty of Health Sciences. University of Sydney, NSW, Australia.

Methods: A search was conducted for randomized controlled trials (RCTs), controlled trials, uncontrolled clinical trials, case series and cross-over studies involving exercise interventions that included a combination of aerobic and strength components, either in circuit-mode or in sequence for people with SCI. Methodological quality was independently rated using the PEDro scale and key findings were extracted from trials by two reviewers.

Results: The search identified 7981 abstracts, from which nine trials met the inclusion criteria. From the nine selected trials, seven reported aerobic outcomes, two of which showed a statistically significant within-group difference in aerobic fitness. Five studies reported muscle strength outcomes, four of them showed a statistically significant within-group mean difference on at least one outcome measure. Two studies looked at QoL, one of them found a statistically significant between-group difference on one outcome measure.

Conclusion: Our systematic review showed that literature on SCI population is scarce, of low quality and findings of existing studies are inconsistent. Thus, further RCTs with larger number of participants are needed to make a definite conclusion about the influence of combined aerobic and muscle strength training on aerobic fitness, muscle strength and QoL in people with SCI.

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INTRODUCTION

Rationale

A spinal cord injury (SCI) leads to dramatic changes in a person's lifestyle. As a result of a spinal cord lesion, physical impairments arise that have a negative impact on the ability of the individual to perform activities within the range considered 'normal' for a human being, consequently diminishing physical functioning (that is, the execution of a task, such as transfer from the wheelchair to the bed) and quality of life (QoL).^{1–3} Exercise interventions are widely available that deal with two important physical impairments: low aerobic fitness and reduced muscle strength and endurance.

Aerobic fitness is reduced after SCI due to impaired redistribution of arterial blood, venous blood pooling below the level of the spinal cord lesion (that is, deep venous thrombosis),⁴ altered cardiovascular autonomic control⁴ and a more sedentary lifestyle⁵ in comparison to able-bodied people.⁶ Muscle strength is decreased because neurological input to the affected muscles that retain partial innervation is deficient, leading to the loss of normal activation timing and force-generating capacity.⁷ Secondary to the loss of neural inputs are negative musculoskeletal adaptations such as transformation to faster muscle fibers (IIa, IIb)⁷ increased contractile speed and increased fatigue in

partially paralyzed and also innervated muscles in people with SCI.⁷ Moreover, lack of training of innervated muscles may compromise physical function resulting in physical and QoL impairments.^{8,9} By improving these physical impairments (that is, low aerobic fitness and reduced muscle strength to partial innervated and innervated regions), exercise interventions aim to impact positively on the functional outcomes and QoL, becoming the ultimate goal of post-traumatic rehabilitation.^{10–12} However, finding an intervention that is effective in targeting both muscle strength and aerobic fitness, and one that can be performed in a short period of time is challenging.

Combined aerobic and strength conditioning is potentially useful because it can improve both impairments, as well as improve functional outcomes in a relatively short period of time. Such combined-mode training may also be cost effective, as it can be performed in any community gym, that is adapted to wheelchair use. Previous studies that have investigated this type of intervention demonstrated improvements in aerobic fitness and/or muscle strength.^{13–18} In addition, some previous reports have found that combined-mode interventions may also be effective for improving functional abilities and QoL.^{11,14–16,18,19} Nevertheless, the findings of these previous investigations have not been subject to the rigors of

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systematic review or meta-analysis techniques to arrive at a definite conclusion as to their physiological benefits or clinical efficacy. Although many systematic reviews have analyzed physical fitness in people with SCI, these have encompassed any general physical exercise interventions, including either aerobic fitness or muscle strength training in isolation, but none specifically have investigated the combination of these two.^{10,20–24} Therefore, it is still unclear whether this type of combined-mode exercise intervention achieves improvements in physical impairments affecting exercise capacity, functional outcomes or QoL in people with SCI who undertake them.

Objective

The aim of this systematic review was to investigate whether combined aerobic training and muscle strength conditioning is effective for improving the aerobic fitness, muscle strength, functional outcomes and/or QoL in people with SCI.

METHODS

Eligibility criteria

The inclusion criteria were, as follows:

Type of study: to be included, studies needed to be randomized controlled trials (RCTs), controlled trials, uncontrolled clinical trials, case series or cross-over studies. For cross-over designs, studies were only included if there was a minimum of 6 weeks 'wash-out' between conditions. Theses and doctoral dissertations were not included in this systematic review. For studies that included a control arm, the control arm could be of no activity, sham exercise or regular physiotherapy treatments.

Type of participants: published studies with participants aged 18 years and older, with a SCI of traumatic or non-traumatic origin, complete or incomplete sensorimotor function (ASIA Impairment Scale grade A–D) were considered for inclusion. Only studies with participants deemed chronic SCI (that is, > 6 months after injury) were included.

Type of interventions: to be included in this review, studies had to employ an exercise intervention that included a combination of aerobic and strength components, either in circuit training or in sequence training. Circuit training was defined as any exercise program in which a series of different exercises were arranged into components and the participant moved quickly from one component to another with a minimum recovery between them. Sequence training was defined as a single aerobic exercise modality followed by a strength mode (or vice versa), repeated not more than two times in the same session. The aerobic component had to involve exercising the large muscles of the body dynamically for a sufficient duration of time to raise exercise heart rate to a steady-state level (for example, biking, arm cranking, stepping and rowing). The strength component had to involve a voluntary contraction of muscle against a force through the use of free weights, different machines or resistive devices, with the movements controlled and carefully defined. The exercise programs needed to last for at least 3 weeks, with at least two sessions per week conducted for a minimum of 30 min per session.

Studies were excluded if the intervention was not typical of community-based exercise interventions, which commonly deploy only voluntary muscle contractions. For example, studies were excluded if the interventions involved any of the following: functional electrical stimulation assisted walking, functional electrical stimulation evoked exercise or exercise with partial body weight support. These therapies are usually not available in a community-based exercise setting, thus becoming the reason for these exclusions.

Type of outcomes: to be included, studies needed to report any of the following outcome variables at baseline and post intervention: aerobic fitness (often expressed as peak oxygen uptake; $\text{VO}_{2\text{peak}}$), muscle strength (often expressed as a maximum weight lifted; 1RM), functional outcomes or QoL. Any assessment tool that measured these variables was included.

Search strategy

Studies were identified by searching the following electronic databases: PEDro, Web of Science, MEDLINE via OvidSP, AMED—Allied and Complementary

Medicine via OvidSP, Cinahl via Ebsco and Scopus from earliest record till February, 2013. No language limit was applied. The search combined terms covering the areas of exercise and SCI (see Supplementary Appendix 1—MEDLINE search strategy). Reference lists of all the retrieved publications were also manually searched for further eligible reports if not located via bibliographic search engines.

Study selection

After eliminating duplications, the search results were screened independently by two authors of this review (VB and CO) against the eligibility criteria. Those references that could not be eliminated by title or abstract were retrieved and independently reviewed by each of the two reviewers. Disagreements were resolved by discussion or by a third reviewer (JR). Abstracts were included only if they contained all of the required information. Non-English language papers were translated. Some publications required extra information before a decision could be made on their inclusion. For those, the primary or senior authors were contacted via e-mail to provide the requisite information. Papers were discarded if the main author could not be contacted or failed to provide sufficient information about the study.

Data extraction

One reviewer extracted the following data from each included trial: (i) study design, including control condition; (ii) characteristics of trial participants, including age, gender, time since injury and body mass index; (iii) type of intervention, including type, intensity, duration and frequency of aerobic and strength components; (iv) type of outcome measure, including the aerobic and muscle strength outcomes, function and QoL measures. The second reviewer checked the extracted data. Disagreements were resolved by discussion between the two reviewers; if no agreement could be reached, a third reviewer was involved to reach consensus.

Assessment of study quality

The quality of each trial was independently assessed by two reviewers using the Physiotherapy Evidence Database (PEDro) scale.²⁵ Any disagreements were resolved by an independent third person. The PEDro scale assesses 10 key design features important for minimizing bias and interpreting between-group differences. Higher scores reflect better-quality trials. Ratings were based on the written text and on information provided by the main authors through communication.

Data analysis

All studies provided sufficient data to enable calculation of mean difference (MD) and standardized mean difference (SMD: Hedges's *g*) and 95% confidence intervals (CIs). In all trials, data collected at the beginning and at the end of the intervention period were extracted. In trials that included a control arm, data were extracted for both intervention and control groups. In trials with no control group, only baseline and end of intervention data from intervention group were extracted. For RCTs or controlled trials both within-group and between-group MD and SMD (Hedges's *g*) with 95% CI were calculated for each continuous outcome. For trials with no control group, within-group MD and SMD (Hedges's *g*) with 95% CI were calculated. Data were extracted from figures and authors were contacted to clarify ambiguities if necessary and feasible.

Forest plots were created using the SMD (Hedges's *g*) and 95% CI to enable a visual comparison across all the studies that reported outcomes within a category (that is, aerobic outcomes, muscle strength outcomes and so on). For those outcomes that were measured homogeneously across studies (that is, muscle strength and QoL), forest plots were also created using MD and 95% CI. All forest plots were created for within-group comparisons and where possible for between-group comparisons. The 95% CI associated with the within-group and between-group MD for each outcome was used to determine whether the effect of the intervention was significant or not within a study. A meta-analysis was not appropriate due to the heterogeneity of exercise prescriptions, outcomes assessed and measurement tools of the included studies. Forest plots of within and between-group differences for all studied outcomes can be found in Figures 2–8.

RESULTS

The original search located 7981 references for SCI. After removal of duplicates and elimination of papers based on the eligibility criteria, nine studies remained. Studies were eliminated based on the following reasons (Figure 1):

- Not a training intervention ($n=27$)
- Not an aerobic plus muscle strength intervention ($n=60$)
- Not the target population ($n=9$)
- Not the criteria intervention length ($n=3$)

- None of the criteria outcomes ($n=4$)
- Article could not be located ($n=2$)

From the nine articles that were selected, three studies were part of a single original study.^{15,17,19} Of these three, we discarded one because it did not match the outcome selection criteria.¹⁷ For the other two, we presented the data for the first original study¹⁹ as the second study used a subset of participants from the original one¹⁵ (personal communication with the lead author). We contacted four authors for further information. All responded and one¹⁴ provided numerical

Figure 1 Flow diagram SCI.

Figure 2 Within-group SMD (Hedges's *g*) and 95% CI for aerobic fitness outcomes.

#Values in lbs were converted to kg

Figure 3 Within-group MD and 95% CI for muscle strength outcomes.

Figure 4 Within-group SMD (Hedges's *g*) and 95% CI for muscle strength outcome.

Figure 5 Within-group MD and 95% CI for QoL outcomes.

data that were not presented in the published paper. We were unable to find any contact information for one of the author.²⁶

Characteristics of the selected publications

Types of study. Nine studies were selected. Only two studies were RCTs published in English.^{11,14} One study was a case series.¹³ The rest

of the studies analyzed measures pre and post intervention with no control group.

Participants. Study participants were both male and female, with four studies recruiting both female and male and two studies recruiting only males (Table 1). Three studies did not report gender. Lesion level

Figure 6 Between-group MD and 95% CI for QoL outcomes.

Figure 7 Within-group SMD (Hedges's *g*) and 95% CI for QoL outcomes.

Figure 8 Between-group SMD (Hedges's *g*) and 95% CI for QoL outcomes.

ranged from C₄ to S₁. Time since injury was from 6 months till 14 years.

Types of interventions. The number of participants in each study ranged from 6 to 34. Seven studies used aerobic and muscle strength in sequence training (Table 2). The duration of the intervention

ranged from 7 weeks to 9 months. Sessions were usually between 2–3 times per week and duration of the session varied from 30 to 60 min. Only two studies used circuit training. In all studies, the aerobic component involved either arm crank ergometry or wheelchair propulsion. Five studies used arm crank ergometry.^{11,14,15,18,19,27} Three studies used wheelchair propulsion.^{13,16,26} The dose of aerobic exercise

Table 1 Participants' characteristics

Study	Sample size	Gender	Age (y) mean $\pm$ s.d. or range (y)	Lesion level	AIS class	Time post-injury mean $\pm$ s.d. or range	Study design
Hicks <i>et al.</i> ¹⁴	34 (Ex: <i>n</i> =21 Con: <i>n</i> =13)	23 male/ 11 female ^a	Ex: 36.9 $\pm$ 11.4 (19–65) Con: 43.2 $\pm$ 9.3 (29–63)	Ex: Tetra: <i>n</i> =11 (C ₄ –T ₂) Para: <i>n</i> =10 (T ₃ –S ₁) Con: Tetra: <i>n</i> =7 (C ₄ –C ₇) Para: <i>n</i> =6 (T ₇ –L ₂)	Ex: A: <i>n</i> =6 B: <i>n</i> =3 C: <i>n</i> =6 D: <i>n</i> =6 Con: A: <i>n</i> =7 B: <i>n</i> =0 C: <i>n</i> =3 D: <i>n</i> =3	Ex: 7.7 $\pm$ 6.4 (1–22) Con: 12.1 $\pm$ 7.3 (3–24) (y)	Randomized controlled trial
Martin Ginis <i>et al.</i> ^{11b}	34 (Ex: <i>n</i> =21 Con: <i>n</i> =13)	23 male/ 11 female	38.6 $\pm$ 11.7		Complete: 14 Incomplete: 13	10.4 $\pm$ 11.79 (y)	Randomized controlled trial
Duran <i>et al.</i> ¹³	13	12 male/ 1 female	26.3 $\pm$ 8.3	T ₃ –T ₆ : <i>n</i> =4 T ₆ –T ₁₂ : <i>n</i> =9	A: <i>n</i> =11 B: <i>n</i> =1 C: <i>n</i> =1	10 (months)	Case series
Jacobs <i>et al.</i> ^{15c}	6		35.7 $\pm$ 9.8	T ₅ –T ₁₂		6.0 $\pm$ 4.7 (months)	Repeated measures
Jacobs <i>et al.</i> ¹⁹	10		39.4 $\pm$ 6.0	T ₅ –L ₁		7.3 $\pm$ 6.0 (months)	Repeated measures
Keyser <i>et al.</i> ¹⁶	27 (17 SCI) ^d		41 $\pm$ 10	No upper limb impairment <i>n</i> =20 Upper limb impairment: <i>n</i> =7			Repeated measures
Nash <i>et al.</i> ¹⁸	7	Male	35–58	T ₅ –T ₁₂	A and B	13.1 $\pm$ 6.6 (y)	Repeated measures
Sabbag <i>et al.</i> ²⁶	Ex: 6 SCI Con: 6 healthy sedentary	Male	Ex: 31.5 $\pm$ 10.5 Con: 31.3 $\pm$ 10.2	T ₁ and below		1 (y)	Repeated measures
Nilsson <i>et al.</i> ²⁷	12 (11 SCI, 1 poliomyelitis)		36 (22–55)	C ₆ –C ₇ : 1 C ₇ –T ₁ : 1 T ₄ : 1 T ₁₁ : 1 T ₁₁ –T ₁₂ : 3 T ₁₂ : 3 T ₁₂ –L ₁ : 2	Complete: 10 Incomplete: 2	10 (4–19) (y)	Repeated measures

Abbreviations: Con, control; Ex, exercise; SCI, spinal cord injury; Sup, supervised; Unsup, unsupervised.

^aNot reported, but presumed from Martin Ginis *et al.*¹¹^bPart of the same population from another study, same participants from Hicks *et al.*¹⁴ data after 3-month intervention.^cThis study used a subset of participants from Jacobs *et al.*¹⁹ therefore the outcomes are reported from Jacobs *et al.*¹⁹ only.^dNo information provided from the 17 SCI participants.

was progressively increased from 15 to 40 min for duration and maintaining an intensity of between 40 and 70% of peak heart rate (HR_{peak}) in most of the studies.

Types of outcomes. For the muscle strength component a variety of exercises involving the main muscles of the upper body were performed using weight machines and elastic bands. Examples of the exercises were the military press, latissimus dorsi pull-down, horizontal row and biceps curls.²⁸

Methodological quality

The quality of studies was based on the PEDro scale. Studies scoring 9–10 on PEDro scale are considered of 'excellent' quality, scores ranging from 6 to 8 are considered of 'good' quality. Scores ranging from 4 to 5 are of 'fair' quality and finally studies, where scores are below 4 are of 'poor' quality.²⁹

Only one RCT scored in each of the 'fair'¹⁴ and 'good'¹¹ categories based on the PEDro scale. The rest of the studies scored between 0 and 3 on the PEDro scale, showing a 'poor' level of quality. None of the

studies utilized concealed allocation and blinding of all participants, therapists and all assessors. Two studies specified the eligibility criteria.^{11,13} Two studies allocated subjects randomly, had baseline similarity and reported between-group statistics.^{11,14} Another two studies analyzed the 'intention to treat'.^{11,26} Four studies measured key outcomes in more than 85% of the initial subjects.^{11,14,18,26} Finally, five studies provided point measures and measures of variability for at least one key outcome.^{11,14,16,18,26}

Study outcomes

All studies provided sufficient data to enable calculation of MD and SMD (Hedges's *g*) and 95% CI for outcomes related to aerobic fitness, muscle strength and QoL. None of the included studies described any functional or physical activity outcomes. The aerobic outcome most often reported was VO_{2 peak} with the exception of one study that used the exercise relationship between HR and power output during an arm crank ergometry assessment.¹⁴ The most common outcome measure for muscle strength was weight lifted by each muscle group in kilograms (kg). All of the studies used 1-Repetition Maximum

Table 2 Intervention characteristics

Study	Type intervention	Control	Aerobic component	Strength component	Length of intervention	Intensity	Dosage and progression
Hicks <i>et al.</i> ¹⁴	Aer/Rt in sequence ^a	Yes: education sessions	Arm ergometry	Wall pulley exercises, free weights and equalizer weight machine	9 months	Aerobic: 70% maximum HR RPE: 3–4 Strength: 50% 1RM	Aerobic: starting at 2 bouts of 5–10 min. Progressing to 2 bouts of 15–20 min Strength: starting at 2 sets of each exercise at 50% of 1RM Progressing at 3 sets at 70% or 80% of 1RM after 4 weeks. Resistance loads were reassessed every 6 weeks Aerobic: 15–30 min arm crank ergometry As participant noticed decreases in RPE or HR, workload and/or duration increased Strength: 45–60 min 2 exercises for each muscle group. Abdominals: one exercise First 6–8 sessions 2 sets of 15 reps for each exercise. After 8 sessions, heavier weights according to individual and 3 sets of 10–12 reps Aerobic: from 15–40 min at 40%–80% of maximal HR and Borg scale.
Martin Ginis <i>et al.</i> ^{11b}	Aer/Rt in sequence	Yes: education sessions	Arm ergometry	Wall pulley exercises, free weights and equalizer weight machine	24 sessions. It took between 12–22 weeks for participant to complete those sessions. Sessions were 3 times per week	Aerobic: 70% of maximum effort during baseline testing Strength: heavier weights according to individual. Did not specify intensity	
Duran <i>et al.</i> ¹³	Aer/Rt in sequence	No	Wheelchair propulsion activities	Bench press-Military press- Butterfly press Dumbbells- Shoulder abductors-Abdominals Curl back neck	16 weeks (Aerobic training: 11 weeks plus 4 week adaptation and 1 week enhancement period) 3 × a week 12 weeks	Aerobic: 40% of maximal HR Strength: no information provided	
Jacobs <i>et al.</i> ^{15,19c}	Circuit ^d : isoinertial resistance exercise interspersed with periods of high-cadence, low-resistance AE.	No	Arm ergometry	Equalizer 7000 Multi-Station Exercise System designed for WC users	12 weeks	Aerobic: 49% of participants' VO _{2peak} and 76.8% of their HR peak Strength: 50–60% 1RM	Aerobic: incomplete recovery, monitoring HR not falling to baseline. Strength: 1RM recomputed every 4 weeks for each resistance exercise Sessions lasted approximately 40–45 min in total.
Keyser <i>et al.</i> ¹⁶	Aer/Rt in sequence	No	Simulation wheelchair propulsion motion using elastic bands (Therabands)	Elastic bands (Therabands) graded in thickness for different levels of resistance.	12 weeks 36 sessions	Aerobic: wheelchair motion using a thinner elastic band (Theraband). Strength: wheelchair motion using thicker elastic bands (Therabands)	Aerobic: each repetition lasted 1–2 s with 1–2 s for the return motion. Duration: 20 min HR was self-monitored, if it was below target HR; the thickness of Theraband was increased at the next session. Strength: Resistance was adjusted, using different thickness of Therabands, so the repetitions were between 8 and 12.

Table 2 (Continued)

Study	Type intervention	Control	Aerobic component	Strength component	Length of intervention	Intensity	Dosage and progression
Nash <i>et al.</i> ¹⁸	Circuit	No	Arm crank ergometer	Weight lifting- equalizer 7000 multistation exercise system	16 weeks 3 × a week	Aerobic: high speed, low-intensity endurance activities-arm crank with interposed periods of incomplete recovery (HR not falling to baseline) Strength: 50% 1RM	8–12 repetitions of exercise against maximal resistance. Each repetition lasted 1–2 s with 1–2 s for the return motion. The movements were performed smoothly to obtain continuous resistance for both aerobic and strength components. Aerobic: information not provided Strength: Progressed to 55% and 60% 1RM on weeks 3 and 4 Session lasted 40–45 min in total
Sabbag <i>et al.</i> ²⁶	Aer/Rt in sequence	No	Wheelchair (WC) propelling	Biodelta Theraband equip- ment, bracelets and dumb- bells with various weights.	6 months 2 × a week	Aerobic: HR at cardiopulmonary stress test at anaerobic threshold, HR at respira- tory compensation point	Aerobic: 25 min Strength: 15 min Session lasted approximately 60 min: 10 min warm-up, 25 min WC propel- ling, 5 min active recovery, consisting of 15 min of localized exercise using different strength equipment, 10 min stretching of upper limbs and torso and 5 min of final stretching of exercised muscles.
Nilsson <i>et al.</i> ²⁷	Aer/Rt in sequence	No	Cycle ergometer for upper extremities	Triceps in both supine and sitting. Biceps training. Abdominals. Medicine ball training	7 weeks 3 × a week	Aerobic: HR at maximal level 3 × 4-min periods with 3 min rest between Strength: dynamic strength and endurance arms and trunk	Aerobic: work load increased to maintain HR near maximal level Strength: No information provided

Abbreviations: Aer, aerobic; HR, heart rate; Rt, resistance training; 1RM, 1-repetition maximum; RPE, rating of perceived exertion.

^aAerobic and resistance training in sequence: combination of an aerobic bout followed by a strength bout.^bPart of the same population from another study, same participants from Hicks *et al.*¹⁴ data after 3-month intervention.^cThis study used a subset of participants from Jacobs *et al.*¹⁹ therefore the outcomes are reported from Jacobs *et al.*¹⁹ only.^dCircuit-mode: any exercise program in which a series of different activities were arranged in sets and the participant moved quickly from one set to another with a minimum of rest between sets.

(1RM) in kilograms to express muscle strength outcomes. One study used an imperial measure of weight (pounds), but this was converted to kilograms for the presentation in the forest plot.¹⁹

Aerobic fitness outcomes

Seven studies reported aerobic outcomes. One of the RCT studies of 'fair' quality that used a twice weekly circuit resistance in combination with arm ergometry intervention, showed a significant within-training group effect on aerobic fitness with MD (95% CI) of 13.8 b.p.m. W^{-1} (0.63–26.9) and between-group effect on aerobic fitness with MD (95% CI) value of 13.1 b.p.m. W^{-1} (0.2–25.98) but only for participants with tetraplegia (Table 3).¹⁴

Four studies of poor quality and with no control groups found no statistically significant within-group improvements in aerobic measures.^{16,18,26,27} The MD (95% CI) from Keyser *et al.* was 11.0 $ml\ min^{-1}$ (–197.6 to 219.6) for participants with no upper limb impairment and 5.0 $ml\ min^{-1}$ (–332.34 to 342.34) for participants with upper limb impairment. The MD (95% CI) from Nash *et al.* was 1.0 $ml\ kg^{-1}\ min^{-1}$ (–4.05 to 6.05) and the MD (95% CI) from Sabbag *et al.* was 0.19 $l\ min^{-1}$ (–0.28 to 0.66).

One study of 'poor' quality showed a statistically significant within-group difference in aerobic fitness, with a MD (95% CI) of 20 W (3.49–36.5) and a SMD (95% CI) of 0.90 (0.11–1.68).¹³ Another study showed also a statistically significant within-group difference, with a MD (95% CI) of 0.43 $l\ min^{-1}$ (0.19–0.66) and a SMD (95% CI) of 1.53 (0.56–2.49) (19). In this case the dose for aerobic exercise was reported, which was progressively increasing in duration from 15 to 40 min and from 40 to 80% of HR_{max} . Figure 2 shows the forest plot for aerobic fitness outcomes.

Muscle strength outcomes

There is some evidence regarding positive muscle strength outcomes (Table 4). Five studies investigated the effectiveness of exercise training on muscle strength. Most of these studies showed statistically significant within-group differences in muscle strength on some of the muscle groups assessed.

One study¹⁸ had significant within-group differences for the following upper limb exercises: horizontal row exercise with a MD (95% CI) of 35.5 kg (26.6–44.3); overhead press with a MD (95% CI) of 20.5 kg (3.9–37.01); horizontal butterfly (pectoralis major and minor) with a MD (95% CI) of 23.6 kg (12.7–34.4); biceps curl with a MD (95% CI) of 11.4 kg (5.5–17.2); latissimus dorsi pull-down with a MD (95% CI) of 24.1 kg (12.5–35.6); and triceps extension with a MD (95% CI) of 25.9 kg (16.78–35.01).

Some statistically significant within-group differences were found in another study of 'poor' quality for most of the muscle strength outcomes. The most distinctive results in this case, were found on triceps dips with a MD (95% CI) of 39.0 lb (11.61–66.3) horizontal row with MD (95% CI) 40.4 lb (4.6–76.1) and latissimus dorsi pull-down with MD (95% CI) 33.2 lb (11.4–54.9).¹⁹

The only 'fair' quality study that used a control group reported statistically significant improvements in muscle strength only on one of the muscle groups assessed. In this case, the within-group MD (95% CI) was 4.5 kg (0.93–8.06) and 4.3 kg (0.10–8.49), for right and left biceps, respectively. A significant between-group effect was found for right biceps only with a MD (95% CI) of 4.6 kg (0.38–8.8).¹⁴ Figures 3 and 4 show the forest plots for muscle strength outcomes.

Table 3 Aerobic fitness outcomes

Study	Aerobic measure	Population	Pre Con (mean ± s.d.)	Post Con (mean ± s.d.)	Pre Ex (mean ± s.d.)	Post Ex (mean ± s.d.)	Within-training group MD (95% CI) ^a	Between-group MD (95% CI) ^a	Within-training group SMD (Hedges's g)	Between-group SMD (Hedges's g and 95% CI) ^a	Study reported a sta- tistical difference?
Hicks <i>et al.</i> ¹⁴	Relationship between HR/ power output (b.p.m. W^{-1}) ^b	Tetraplegics	13.7 ± 10.7	13.0 ± 13.8	21.8 ± 15.9	8.0 ± 4.5	13.8 (0.63 to 26.9)	13.1 (0.2 to 25.98)	0.98 (–0.012 to 1.99)	0.91 (–0.03 to 1.86)	Yes
Keyser <i>et al.</i> ¹⁶	Relationship between HR/ power output (b.p.m. W^{-1})	Paraplegics	3.3 ± 1.3	3.2 ± 1.1	4.8 ± 3.9	2.9 ± 1.5	1.9 (–2.11 to 5.9)	1.8 (–1.06 to 4.66)	0.51 (–0.5 to 1.61)	0.60 (–0.3 to 1.58)	Yes
Duran <i>et al.</i> ¹³	Maximum resistance (W)	Tetraplegics			90 ± 24	110 ± 18.6	20 (3.49 to 36.5)		0.90 (0.11 to 1.68)		Yes
Jacobs <i>et al.</i> ^{13,15}	VO_{2peak} ($l\ min^{-1}$)	Tetraplegics			1.45 ± 0.22	1.88 ± 0.31	0.43 (0.19 to 0.66)		1.53 (0.56 to 2.49)		Yes
Keyser <i>et al.</i> ¹⁶	VO_{2peak} ($l\ min^{-1}$)	No upper limb impairment			1.126 ± 363	1.115 ± 308	11.0 (–197.6 to 219.6)		0.032 (–0.575 to 0.64)		Yes
Keyser <i>et al.</i> ¹⁶	VO_{2peak} ($l\ min^{-1}$)	Upper limb impairment			866 ± 323	871 ± 321	5.0 (–332.34 to 342.34)		0.015 (–0.96 to 0.91)		No
Nash <i>et al.</i> ¹⁸	VO_{2peak} ($l\ min^{-1}$)	Tetraplegics			1.64 ± 0.45	1.81 ± 0.54	0.17 (–0.35 to 0.69)		0.320 (–0.66 to 1.30)		No
Sabbag <i>et al.</i> ²⁶	VO_{2peak} ($ml\ kg^{-1}\ min^{-1}$)	Not specified			18.8 ± 4.8	19.8 ± 4.1	1.0 (–4.05 to 6.05)		0.207 (–0.84 to 1.25)		No
Nilsson <i>et al.</i> ²⁷	VO_{2peak} ($l\ min^{-1}$)	Not specified			1.88	2.07	0.19 (–0.287 to 0.667)		0.391 (–0.6 to 1.38)		No

Abbreviations: CI, confidence interval; Con, control; Ex, exercise; HR, heart rate; MD, mean difference; SMD, standardized mean difference.

^aThese variables were calculated as control-exercise, not exercise-control.

^bSubmaximal arm crank test.

Table 4 Muscle strength outcomes

Study	Strength measure	Muscle group	Pre Con (mean $\pm$ s.d.)	Post Con (mean $\pm$ s.d.)	Pre Ex (mean $\pm$ s.d.)	Post Ex (mean $\pm$ s.d.)	Within- training group MD (95% CI)	Between- group MD (95% CI)	Within- training group SMD (Hedges's g and 95% CI)	Between- group SMD (Hedges's g and 95% CI)	Study reported a statistical difference?
Hicks <i>et al.</i> ¹⁴	Weight lifted (kg)	Right chest	44.2 $\pm$ 20.3	44.0 $\pm$ 21.2	41.4 $\pm$ 28.2	49.5 $\pm$ 31.5	8.1 (-13.30 to 29.50)	8.3 (-10.30 to 26.90)	0.26 (-0.44 to 0.98)	0.30 (-0.37 to 0.98)	Yes
		Left chest	46.4 $\pm$ 20	45.8 $\pm$ 20.3	41.6 $\pm$ 27.8	51.3 $\pm$ 29.6	9.7 (-11.02 to 30.42)	10.3 (-7.58 to 28.18)	0.33 (-0.38 to 1.04)	0.38 (-0.29 to 1.07)	Yes
		Right biceps	13.5 $\pm$ 4.2	13.2 $\pm$ 6.2	13.8 $\pm$ 4.8	18.1 $\pm$ 7.3	4.3 (0.10 to 8.49)	4.6 (0.38-8.8)	0.72 (-0.00 to 1.46)	0.73 (0.04 to 1.43)	Yes
		Left biceps	13.4 $\pm$ 4.6	15.1 $\pm$ 5.6	13.2 $\pm$ 4.0	17.7 $\pm$ 6.3	4.5 (0.93 to 8.06)	2.8 (-0.93 to 6.53)	0.89 (0.15 to 1.64)	0.50 (-0.17 to 1.19)	No
		Right anterior deltoid	7.4 $\pm$ 3.4	7.4 $\pm$ 4.5	6.6 $\pm$ 3.4	8.1 $\pm$ 3.7	1.5 (-1.05 to 4.05)	1.5 (-1.09 to 4.09)	0.41 (-0.30 to 1.13)	0.39 (-0.29 to 1.07)	No
Duran <i>et al.</i> ¹³		Left anterior deltoid	7.0 $\pm$ 3.8	7.5 $\pm$ 4.4	6.5 $\pm$ 3.8	7.8 $\pm$ 3.4	1.3 (-1.3 to 3.97)	0.80 (-1.8 to 3.44)	0.34 (-0.37 to 1.06)	0.20 (-0.47 to 0.88)	No
	Weight lifted (kg)	Bench press			42.7 $\pm$ 17.3	62.5 $\pm$ 20	19.8 (5.4 to 34.17)		1.02 (0.2 to 1.8)		Yes
		Military press			60 $\pm$ 18.2	68.3 $\pm$ 17.8	8.3 (-5.5 to 22.1)		0.44 (-0.3 to 1.2)		Yes
		Butterfly press			52.3 $\pm$ 12.6	64.2 $\pm$ 12.8	11.9 (2.1 to 21.6)		0.9 (0.12 to 1.69)		Yes
	1RM maximal strength (lb)	Military press			127 $\pm$ 32.1	151.6 $\pm$ 38.2	24.6 (-6.3 to 55.5)		0.66 (-0.19 to 1.53)		Yes
Jacobs <i>et al.</i> ^{15,19}		Horizontal row			194.2 $\pm$ 37.2	234.6 $\pm$ 44.0	40.4 (4.6 to 76.1)		0.95 (0.06 to 1.8)		Yes
		Pec deck			133.8 $\pm$ 34.2	162 $\pm$ 34.3	28.2 (-1.8 to 58.22)		0.78 (-0.08 to 1.66)		Yes
		Preacher curls			45.4 $\pm$ 8.0	50.8 $\pm$ 9.2	5.4 (-2.1 to 12.95)		0.60 (-0.2 to 1.4)		No
		Latissimus pull down			143.4 $\pm$ 23.2	176.6 $\pm$ 26.4	33.2 (11.4 to 54.9)		1.2 (0.35 to 2.2)		Yes
		Dips			129.3 $\pm$ 32.8	168.3 $\pm$ 29.6	39 (11.6 to 66.3)		1.19 (0.27 to 2.11)		Yes
Nash <i>et al.</i> ¹⁸		Overhead press			47.7 $\pm$ 11.5	68.2 $\pm$ 19.1	20.5 (3.9 to 37.01)		1.21 (0.13 to 2.2)		Yes
	Weight lifted (kg)	Horizontal row			59.5 $\pm$ 6.0	95 $\pm$ 10.3	35.5 (26.6 to 44.3)		3.9 (2.1 to 5.7)		Yes
		Horizontal butterfly			58.2 $\pm$ 7.2	81.8 $\pm$ 12.8	23.6 (12.7 to 34.4)		2.1 (0.86 to 3.38)		Yes
		Biceps curl			27.7 $\pm$ 4.8	39.1 $\pm$ 6.3	11.4 (5.5 to 17.2)		1.9 (0.69 to 3.11)		Yes
		Latissimus dorsi pull down			62.3 $\pm$ 10.5	86.4 $\pm$ 11.6	24.1 (12.5 to 35.6)		2.03 (0.8 to 3.2)		Yes
Nilsson <i>et al.</i> ²⁷		Triceps			59.1 $\pm$ 8.7	85.0 $\pm$ 8.7	25.9 (16.78 to 35.01)		2.78 (1.36 to 4.21)		Yes
	Maximal dynamic strength (kg)	Triceps			63.8	75.8	12.0 (-2.49 to 26.4)		0.86 (-0.2 to 1.9)		No

Abbreviations: CI, confidence interval; Con, control; Ex, exercise; HR, heart rate; MD, mean difference; SMD, standardized mean difference; 1RM, 1-repetition maximum.

Table 5 QoL outcomes

Study	QoL measure	Pre Con (mean $\pm$ s.d.)	Post Con (mean $\pm$ s.d.)	Pre Ex (mean $\pm$ s.d.)	Post Ex (mean $\pm$ s.d.)	Within- training group MD (95% CI)	Between-group MD (95% CI)	Within- training group SMD (Hedges's g and 95% CI)	Between-group SMD (Hedges's g and 95% CI)	Study reported a statistically significant difference?
Hicks <i>et al</i> , ¹⁴	SPF	22.6 $\pm$ 8.79	27.9 $\pm$ 7.65	29.0 $\pm$ 6.18	32.2 $\pm$ 7.24	3.2 (-1.58 to 7.9)	-2.1 (-6.85 to 2.65)	0.47 (-0.24 to 1.19)	-0.29 (-0.97 to 0.38)	Yes
	SPA	13.9 $\pm$ 7.19	17.5 $\pm$ 6.92	17.4 $\pm$ 5.68	20.5 $\pm$ 6.60	3.1 (-1.2 to 7.47)	-0.5 (-5.01 to 4.01)	0.50 (-0.21 to 1.22)	-0.07 (-0.75 to 0.60)	No
	Pain	5.9 $\pm$ 2.38	6.5 $\pm$ 1.79	5.1 $\pm$ 2.02	4.6 $\pm$ 1.70	0.5 (-0.9 to 1.9)	-1.1 (-2.47 to 0.27)	0.25 (-0.46 to 0.96)	-0.54 (-1.22 to 0.14)	Yes
	Stress	41.4 $\pm$ 11.02	41.5 $\pm$ 11.14	36.7 $\pm$ 12.52	31.4 $\pm$ 10.59	5.3 (-3.38 to 13.9)	-5.4 (-13.3 to 2.52)	0.43 (-0.28 to 1.15)	-0.46 (-1.14 to 0.22)	Yes
	Depression	14.4 $\pm$ 8.04	19.1 $\pm$ 12.51	10.1 $\pm$ 8.29	10.1 $\pm$ 11.91	0.00 (-7.03 to 7.03)	-4.7 (-12.12 to 2.72)	0.00 (-0.7 to 0.7)	-0.42 (-1.11 to 0.25)	No
Martin Ginis <i>et al</i> , ¹¹	PQoL	62 $\pm$ 13.47	61.4 $\pm$ 15.72	69.5 $\pm$ 12	74.9 $\pm$ 14.94	5.4 (-4.1 to 14.9)	6.0 (-3.75 to 15.75)	0.40 (-0.3 to 1.12)	0.41 (-0.26 to 1.09)	Yes
	Perceived health	2.7 $\pm$ 0.82	3.0 $\pm$ 1.05	3.7 $\pm$ 1.01	4.1 $\pm$ 1.0	0.4 (-0.33 to 1.13)	0.10 (-0.58 to 0.78)	0.38 (-0.33 to 1.10)	0.09 (-0.5 to 0.77)	Yes
	Pain	5.85 $\pm$ 2.05	7.09 $\pm$ 2.77	5.10 $\pm$ 1.79	4.95 $\pm$ 2.15	0.15 (-1.07 to 1.37)	-1.39 (-2.9 to 0.12)	0.07 (-0.53 to 0.68)	-0.61 (-1.3 to 0.07)	No
	Stress	42.6 $\pm$ 11.04	44 $\pm$ 11.2	37.52 $\pm$ 10.21	34.16 $\pm$ 7.64	3.36 (-2.27 to 8.99)	-4.67 (-11.65 to 2.13)	0.36 (-0.25 to 0.97)	-0.46 (-1.15 to 0.21)	No
	Self efficacy	72.3 $\pm$ 16.91	79.09 $\pm$ 15.78	93.81 $\pm$ 56.5	77.39 $\pm$ 23.3	16.4 (-10.89 to 43.7)	-23.21 (-50.98 to 4.56)	0.36 (-0.24 to 0.97)	-0.56 (-1.25 to 0.12)	No
	Perceived control	3.31 $\pm$ 0.85	3.63 $\pm$ 0.81	3.76 $\pm$ 1.14	3.89 $\pm$ 0.81	0.13 (-0.48 to 0.74)	-0.19 (-0.84 to 0.46)	0.12 (-0.48 to 0.73)	-0.19 (-0.87 to 0.48)	No
	PQoL	63.92 $\pm$ 14.95	55.18 $\pm$ 15.58	66.13 $\pm$ 13.22	68.84 $\pm$ 12.08	2.71 (-5.16 to 10.58)	11.45 (1.96 to 20.93)	0.20 (-0.40 to 0.81)	0.81 (0.11 to 1.51)	No
	Depression	12.5 $\pm$ 8.32	19.27 $\pm$ 13	11.7 $\pm$ 7.77	10.16 $\pm$ 6.87	1.54 (-3.02 to 6.10)	-8.31 (-14.59 to -2.02)	0.20 (-0.4 to 0.81)	-0.89 (-1.6 to -0.18)	No
	Physical functioning	22.57 $\pm$ 8.09	19.6 $\pm$ 6.55	26.21 $\pm$ 8.86	30.6 $\pm$ 5.98	4.39 (-0.34 to 9.12)	7.36 (2.04 to 12.67)	0.56 (-0.05 to 1.18)	0.93 (0.22 to 1.64)	Yes
	Physical appearance	14.08 $\pm$ 7.14	15.43 $\pm$ 6.5	15.43 $\pm$ 5.0	19.9 $\pm$ 5.2	4.47 (1.30 to 7.6)	3.12 (-0.85 to 7.09)	0.86 (0.22 to 1.49)	0.53 (-0.15 to 1.21)	Yes

Abbreviations: CI, confidence interval; Con, control; Ex, exercise; MD, mean difference; PQoL, perceived quality of life; QoL, quality of life; SMD, standardized mean difference; SPA, satisfaction with physical appearance; SPF, satisfaction with physical function.

Quality of life (QoL) outcomes

Two studies looked at QoL, using different questionnaires to obtain results regarding pain perception, symptom self-efficacy, perceived control, stress, satisfaction with fundamental needs of daily living, perceived health and depression (Table 5).^{11,14} The heterogeneity of the scales used to measure QoL made it difficult to compare the studies. One of the questionnaires used was the Reboussin *et al.* 9-item body satisfaction questionnaire,³⁰ which included Physical Appearance and Physical Functioning. Only one of studies included in this review found a significant effect on physical appearance using the body satisfaction questionnaire, but only for within-group differences with a MD (95% CI) of 4.47 (1.30–7.6).¹⁴ The only between-group significant difference was found for physical functioning, with a MD (95% CI) of 7.36 (2.04–12.67).¹⁴ The Perceived Quality of Life Scale (PQoL) was used by two studies. One study found a statistically significant between-group difference with a MD (95% CI) of 11.45 (1.96–20.93) but the other study did not find a significant effect in the same group of participants, as the MD (95% CI) was of 6.0 (–3.75 to 15.75). Neither study found a statistically significant within-group difference with a MD (95% CI) of 5.4 (–4.1 to 14.9) and 2.71 (–5.16 to 10.5), respectively.^{11,14} Results within-group and between-groups for outcomes such as pain, stress and depression were not significant in either study.^{8,12} See Figures 5–8 for forest plots for QoL outcomes.

DISCUSSION

Overall, the quality of the published evidence surveyed in this review was not sufficiently robust to determine the effectiveness of combined aerobic training and muscle strength conditioning for improving aerobic, muscle strength, QoL and functional outcomes. Some significant positive effects were found for aerobic fitness outcomes, after resistance training was combined with arm crank exercise in a study of ‘fair’ PEDro-denoted quality. However, those results were found in one population only (tetraplegics), so there was little evidence to draw any firm conclusions from this one study.¹⁴ Any other significant findings were noted in studies of poor quality.^{13,19} Muscle strength showed some significant positive outcomes on some of the upper limb muscles assessed, but those results were not consistent, showing only within-group differences on some specific muscles. The ‘fair’ PEDro denoted quality study showed a significant effect for within- and between- groups changes but only on one specific muscle (right biceps). Our findings of low quality levels of evidence among studies related to exercise interventions in people after SCI were similar to findings of other systematic reviews that looked at the effects of exercise training on physical capacities and functional performance in people with SCI.^{10,23,31}

Given our muscle strength results, it seems that the ideal dose would be 50–80% 1RM with progression applied to maintain overload adaptation.¹⁴ It is interesting to highlight that in one study that showed improvements in muscle strength, the strength training dose started with 50% 1RM with the number of sets of exercises also increasing over time.¹⁴ In regards to studies that did not specify a dose, the reason for the inconclusive results could have been that they used light resistance that was subthreshold for a training effect. The other two studies that found significant effects on some of the muscles assessed also specified a training dose starting at 50% of 1RM and increasing progressively up to 60% 1RM.^{18,19} The rest of the studies did not specify an appropriate dose of exercise.^{13,27}

Making comparisons between studies and drawing any conclusions about QoL outcomes is problematic due to the lack of one standard scale and the use of many psychological scales and questionnaires. It has been stated in previous studies that a more concrete and universal

definition of QoL is necessary to make a true comparison between studies.³² The evidence regarding QoL is inconclusive, as only three out of fifteen outcomes showed positive results towards improvements in that domain. Overall, evidence is insufficient to draw a solid conclusion regarding QoL outcomes.^{11,14}

In regards to the general poor quality of the studies, there are some aspects that are worth mentioning. Among aspects that are missing from SCI studies are blinding of subjects and therapists. These missing aspects are due to difficulties in achieving blinding when using exercise interventions. Another aspect missing in most of the studies is specifying the criteria for selection of participants, this is explained by the fact that narrow criteria could lead to low number of participants and most studies tend to use a pool of participants that could be recruited easily from a rehabilitation center or hospital, rather than recruiting participants with SCI from different sites. Having found only two RCT studies that matched our criteria, it could be implied that performing RCT among the SCI population is difficult to accomplish. There is one barrier when working with people with SCI that would make conducting RCT challenging. An individual with a SCI, when being offered a high quality training intervention or being part of a control group, would most likely refuse to take part if allocated to the control group; there are ethical concerns with denying the possibility of some kind of treatment by including a control group in the study.³³

Our inconclusive findings in aerobic fitness, muscle strength and QoL outcomes were similar to the ones identified in previous systematic reviews about physical interventions in people with SCI.^{10,23,32} The differences between our review and those previously published were that (i) our review searched only for people with SCI in a chronic state (more than six months after injury), as we wanted to avoid any influence of natural neurological recovery that happens during the first six months after the injury; and (ii) our review only looked at interventions involving either circuit training or aerobic plus muscle strength training performed in sequence, because we were interested in voluntary exercises that are commonly used in community-based exercise interventions, without the use of any special equipment or devices, such as a treadmill or functional electrical stimulation.^{10,23,32}

Finally, our search criteria did not limit the spinal cord injury level because that would have limited the number of research studies and missed relevant information for this systematic review. Although an aerobic training effect would have not been expected in people with higher lesion levels, a significant effect for aerobic fitness was found in tetraplegics.

Limitations

A limitation of this review was that we excluded thesis and doctoral dissertations, so we may have missed some unpublished studies with valuable data. Another limitation was that some full text articles could not be located, so we could only use the information provided by title and abstract to make the selection of the articles.

CONCLUSION

Overall, the existing literature on the spinal cord injured population relating to the effects of combined aerobic and muscle strength training on aerobic fitness, muscle strength, function and QoL is scarce and of low quality. There is little evidence to support any statement in favor of aerobic fitness improvements after combined aerobic and muscle strength training. The results of this systematic review provide initial evidence of significant improvements in muscle strength after a combined aerobic and muscle strength training.

However, these results are insufficient to draw any definite conclusions. The only conclusion that can be drawn is that the ideal dose for muscle strength training would be 50–80% 1RM with progression applied. As far as QoL is concerned, although the two studies that analyzed this outcome were of ‘fair’ and ‘good’ quality, results were limited and lacked consistency for both within and between-groups differences. Functional outcomes were not described in any of the selected studies. Therefore, conclusions about the effectiveness of combined aerobic and muscle strength training on QoL and function cannot be made.

To advance this field of research, further RCT with larger numbers of participants are needed to make a definite conclusion about the influence of combined aerobic and muscle strength training on aerobic fitness, muscle strength and QoL in people with SCI. It would also be of great importance to include functional assessments in within the RCT as part of the main outcome.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Supplementary Information accompanies this paper on the Spinal Cord website (<http://www.nature.com/sc>)