# Effects of exercise on fitness and health of adults with spinal cord injury: a systematic review

# Effects of Exercise on Fitness and Health of Adults with Spinal Cord Injury: A Systematic Review

Jan W. van der Scheer Ph.D.[1], Kathleen A. Martin Ginis Ph.D. [2], David S. Ditor Ph.D.[3], Victoria Goosey-Tolfrey Ph.D.[1], Audrey L. Hicks Ph.D.[4], Christopher West Ph.D.[5], Dalton L. Wolfe Ph.D.[6]

[1]School for Sports, Exercise and Health Sciences, Peter Harrison Centre for Disability Sport, National Centre for Sport and Exercise Medicine, Loughborough University, LE11 3TU, United Kingdom.
[2]School of Health and Exercise Sciences, University of British Columbia, Kelowna BC, Canada, V1V 1V7; ICORD, University of British Columbia, Vancouver BC, Canada, V5Z 1M9.
[3]Department of Kinesiology, Brock University, St. Catharines, Ontario, Canada, L2S 3A1
[4]Department of Kinesiology, McMaster University, Hamilton, ON, Canada, L8S 4K1
[5]ICORD, University of British Columbia, Vancouver BC, Canada, V5Z 1M9; School of Kinesiology, University of British Columbia, Vancouver BC, Canada, V6T 1Z1
[6]Parkwood Institute, Lawson Health Research Institute, London, ON Canada N6C 0A7

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**Supplemental data**
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**Corresponding author**
Kathleen Martin Ginis, PhD; School of Health and Exercise Sciences, University of British Columbia, Kelowna BC, Canada, V1V 1V7. Phone: +1 250.807.9768. Email: kathleen_martin.ginis@ubc.ca

**Principal Investigator/Guarantor**
Jan W. van der Scheer, PhD; Peter Harrison Centre for Disability Sport, National Centre for Sport and Exercise Medicine, School for Sports, Exercise and Health Sciences, Loughborough University, LE11 3TU, United Kingdom. Phone: +44 (0)1509 227549. Email: j.scheer@lboro.ac.uk

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| David S. Ditor | | X | | X |
| Victoria Goosey-Tolfrey | | X | | X |
| Audrey L. Hicks | | X | | X |
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**Abstract**

**Objective**: To synthesize and appraise research testing the effects of exercise interventions on fitness, cardiometabolic health and bone health among adults with spinal cord injury (SCI).

**Methods:** Electronic databases were searched (1980-2016). Included studies: employed exercise interventions for a period ≥2 weeks; involved adults with acute or chronic SCI; and measured fitness (cardiorespiratory fitness, power output and/or muscle strength), cardiometabolic health (body composition and/or cardiovascular risk factors), and/or bone health outcomes. Evidence was synthesized and appraised using GRADE.

**Results:** 211 studies met the inclusion criteria (22 acute, 189 chronic). For chronic SCI, GRADE confidence ratings were moderate to high for evidence showing exercise can improve all of the reviewed outcomes except bone health. For acute SCI, GRADE ratings were very low for all outcomes. For chronic SCI, there was low-to-moderate confidence in the evidence showing that 2-3 sessions/week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-40 min, plus upper-body strength exercise (3 sets of 10 repetitions at 50-80% 1RM for all large muscle groups) can improve cardiorespiratory fitness, power output and muscle strength. For chronic SCI, there was low-to-moderate confidence in the evidence showing that 3-5 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-44 min can improve cardiorespiratory fitness, muscle strength, body composition, and cardiovascular risk.

**Conclusions:** Exercise improves fitness and cardiometabolic health of adults with chronic SCI. The evidence on effective exercise types, frequencies, intensities and durations should be used to formulate exercise guidelines for adults with SCI.

## INTRODUCTION

Exercise is defined as planned, structured, and repetitive physical activity that is performed to improve or maintain fitness.[1] Among adults living with spinal cord injury (SCI), participation in exercise improves physical fitness (i.e., cardiorespiratory fitness, power output and muscle strength)[2]. Exercise may also have health benefits (e.g., reduced risk of cardiometabolic disease, osteoporosis) through improvements in factors such as body composition, lipid profiles, and bone mineral density.[3, 4] Nevertheless, people with SCI do far less exercise, and are more physically deconditioned than the general population and other disability groups.[5-7] An important first step toward using exercise to improve fitness and health, is formulating and implementing SCI-specific, evidence-based exercise guidelines.

Exercise guidelines are systematically developed statements providing appropriate age- and ability-specific information regarding the course of action required to maintain or enhance fitness, performance or health.[8] Guideline development steps include: systematic review and appraisal of relevant research evidence; drafting guideline recommendations that align with the evidence; review of the guideline recommendations by a multidisciplinary stakeholder team including content-specific experts and end-users; and preparation of a final guideline report and strategy for guideline implementation.[9, 10]

In 2011, these steps informed development of the first SCI-specific, evidence-based exercise guidelines which stipulate that “for important fitness benefits, adults with a SCI should engage in at least 20 min of moderate to vigorous intensity aerobic activity two times per week and strength-training exercises two times per week”.[11] The strength component of the SCI guideline duplicates that of the World Health Organization’s (WHO) guidelines for the general population.[12] However, the aerobic component of the SCI guideline is well below the WHO’s 150 min/week aerobic guideline, an observation that (a) aligns with ‘overwhelming evidence’ that people with disabilities can achieve fitness and health benefits from activity levels well below the 150 min/week threshold[13] and (b) attests to the importance of using SCI-specific evidence to identify the activity thresholds at which people with SCI achieve health and fitness benefits.[14] SCI-specific evidence is also necessary for elucidating the risk of SCI-specific exercise-related adverse events (e.g., upper-body over-use injuries[15], over-heating[16]). Exercise risks versus benefits must be considered during guideline development.[9, 10]

It is also important to keep guidelines current and aligned with best available evidence.[10, 11] In 2011, insufficient high-quality evidence was available to formulate exercise guidelines to improve cardiometabolic or other health outcomes.[11] Reviews since 2011 indicate increased SCI exercise research, particularly in high-quality intervention studies aimed at altering cardiometabolic or bone health.[17-22] However, significant limitations of these reviews include no grading of the confidence in the evidence,[17, 18, 20-22] the use of only one cardiometabolic health outcome (i.e., inflammatory markers),[19] or consideration of only one exercise type.[17, 22] Furthermore, no review has synthesized and appraised exercise prescriptions used in SCI interventions. Exercise prescriptions are the ‘dose’ of exercise given to participants, consisting of exercise type, frequency, intensity and duration,[23] and are the key informational elements of exercise guidelines.[8] A systematic review was undertaken to address these limitations and provide guideline recommendations to inform an update of the 2011 guidelines.[11] The review addressed three questions:

1. Can exercise interventions significantly improve fitness, cardiometabolic or bone health?
2. What specific exercise prescriptions improve fitness, cardiometabolic or bone health?
3. How common are adverse events during exercise interventions?

## METHODS

The review protocol (not registered) and reporting were guided by PRISMA.[18] Pubmed, MEDLINE, PsychINFO, SPORTDiscus, EMBASE, and CINAHL were searched for studies published between 1-1-1980 and 1-1-2016 (appendix e-1) by combining keywords representing SCI (e.g., “spinal cord lesion”, “paraplegia”) with keywords representing exercise interventions (e.g., “physical activity”, “sports”, “exercise”) (table e-1). Language was restricted to English.[19]

### *Study eligibility criteria*

Eligible studies included a sample with at least 50% adults (≥16 years) with traumatic or non-traumatic SCI, excluding multiple sclerosis and spina bifida. Exercise interventions were defined as studies employing any type of exercise, so long as details on type (e.g., upper-body aerobic exercise, ambulation exercise), frequency (e.g., sessions/week), intensity (e.g., % peak oxygen uptake) and duration (e.g., min/session) were reported, while the exercise occurred for ≥2 weeks. Randomized controlled trials (RCTs) were included, along with non-randomized controlled trials, pre-post studies, case-series and prospective, retrospective and cross-sectional cohort studies with a control group (defined in table e-2). Case studies were excluded given their relatively high potential for bias. Studies were included as a controlled study if the comparator for the exercise intervention was a control group not receiving an exercise intervention. Receiving usual care was accepted as a control condition when the exercise group also received this usual care in addition to the exercise intervention. Studies must have included at least one measure from any of the following outcomes: cardiorespiratory fitness, power output, muscle strength, body composition cardiovascular risk factors, and/or bone health (defined in table e-3).

Reviewers from the Spinal Cord Injury Research Evidence (SCIRE) project (http://scireproject.com) conducted the searches and study eligibility screening (figure e-1). Data from eligible studies were extracted by SCIRE reviewers (tables e-4 and e-5) and verified by author JWvdS. Using these data, authors JWvdS, KMG, DD, VG-T, AH or CW coded each study as showing improvements in an outcome or not. Improvement was defined as a statistically significant post-intervention improvement in at least one measure within an outcome. For case-series studies in which statistics were not applied, improvement was defined as all participants improving on one or more outcome measures. If contrasting significant results were found (e.g., for the same outcome, one measure indicated a significant improvement, while another indicated a significant deterioration), the study was designated as providing 'inconclusive results'. Authors JWvdS and KMG verified this process, discussing differences with the other authors until consensus was reached.

### *Risk of bias in individual studies*

Risk of bias in each study was assessed based on strength of the study design and, secondary to that, cut-off scores using the Physiotherapy Evidence Database (PEDro) tool or a modified Downs and Black scale (table e-2).[21-23] This four-level rating system was based on methods developed by SCIRE,[21] and complemented by Downs and Black cut-off scores. For example, Level 1 studies were RCTs with a PEDro score ≥6, while Level 4 studies were uncontrolled pre-post trials with a Downs and Black score <21 (table e-2).

### *Synthesis of evidence*

To provide an overview of the evidence regarding the *general* effects of exercise interventions, for each outcome, an evidence summary was drafted for adults with acute SCI (studies with mean time since injury ≤12 months and/or >50% of participants with SCI ≤12 months; table e-6) and chronic SCI (table e-7).[2] Further demographic/injury breakdown in the summaries was considered inappropriate, given the limited number of high-quality studies providing data only for adults with cervical lesions (three out of the 31 Level 1 or 2 studies; tables e-4 and e-5) or motor incomplete lesions (three Level 1 or 2 studies). Descriptive data (i.e., study participant characteristics, total number of studies, and number of Level 1-4 studies) were summarized for all studies together, as well as for studies that showed improvement, no improvement, or inconclusive results. Each evidence summary was assessed using Grading of Recommendations Assessment, Development, and Evaluation (GRADE).[10, 24] Based on predefined benchmarks (table e-8), GRADE confidence ratings in the evidence (i.e., “high”, “moderate”, “low”, or “very low”) were established for each outcome, and used to formulate a conclusion statement (tables 1 and 2).

The studies were also synthesized to draw conclusions regarding the *specific* exercise prescriptions associated with improvements in each outcome. Evidence summaries were drafted only for those types of exercise that were employed in at least two Level 1 or 2 studies for a given outcome (table e-9); two high-quality studies were considered the minimum support needed to draft a guideline recommendation (cf.[25]). Summaries included participant characteristics, number and quality of the studies, as well as the exercise prescriptions used across the Level 1 and 2 studies, and those used across the Level 3 and 4 studies (tables e-10 and e-11). Next, the exercise prescriptions from the Level 1 and 2 studies showing significant improvements were synthesized into a statement describing the minimum and maximum frequencies, intensities and durations of exercise across these prescriptions. A GRADE confidence rating for this evidence was established, and used to formulate guideline recommendations (tables 3 and 4). Exercise prescriptions from the Level 3 and 4 studies were used in the recommendation only if there were inconsistencies among the Level 1 and 2 studies (see cardiorespiratory fitness in table 3).

For studies describing adverse events resulting from exercise interventions, the following data were tabulated: exercise type, total number of participants, and number of participants reporting no adverse events, “serious” adverse events, or “other” adverse events (tables e-12 and e-13).[27]

## RESULTS

From 13,115 citations, 211 studies (22 for acute SCI, 189 for chronic SCI) met the inclusion criteria (figure e-1).

### *Adults with acute SCI*

Only four studies were Level 1 or 2 studies; the remaining 18 studies were Level 3 or 4 studies (tables e-4 and e-6). Evidence for the different outcomes primarily included young and middle-aged men (across the outcomes: 45-80% men; average age 34-40 y; average time since injury of 5-14 weeks; table e-6). All outcomes included studies of participants with A-D injuries on the American Spinal Injury Association Impairment Scale (AIS) and cervical, thoracic or lumbar lesion levels, except for muscle strength and body composition (no thoracic or lumbar lesions; table e-6). All interventions occurred in supervised rehabilitation or unspecified settings (table e-4). The most common exercise types were upper-body aerobic exercise (7 studies), ambulation exercise (6 studies) and FES cycling (3 studies; table e-4).

GRADE assessments (table 1) revealed a lack of high-quality, consistent, precise and/or direct evidence for the different outcomes (see table e-14 for full narrative descriptions). Overall, there was very low confidence in the evidence showing that exercise can improve any of the reviewed outcomes among adults with acute SCI (table 1). The lack of sufficient Level 1 or 2 studies (table e-9) prohibited drafting guideline recommendations regarding exercise prescriptions. Adverse events were described in only three studies involving 204 participants (no adverse events: n=202; lightheadedness during functional electrical stimulation [FES] cycling: n=2; table e-12).

***Adults with chronic SCI***

Thirty-one studies were Level 1 or 2 studies; the remaining 158 studies were Level 3 or 4 studies (tables e-5 and e-7). Evidence for the outcomes primarily included young and middle-aged men (across the outcomes: 75-85% men; average age of 30-34 y; average time since injury of 7-8 y; table e-7). Evidence for all outcomes included participants with AIS A-D and cervical, thoracic or lumbar lesion levels (table e-7). Six studies involved home-based exercise interventions (table e-5). All other interventions occurred in supervised settings (e.g., a lab or rehabilitation centre), or did not specify the setting. Two interventions involved sport practice combined with exercise; the remaining 187 interventions involved exercise only. Despite numerous interventions involving FES cycling (43 studies), FES strength exercise (29 studies), and ambulation exercise (32 studies), there were respectively only one, two and three Level 1 or 2 studies employing these exercise types (tables e-5 and e-9). Other common exercise types were upper-body aerobic exercise (32 studies) and upper-body aerobic plus strength exercise (14 studies), for which there were eight Level 1 or 2 studies (tables e-5 and e-9).

There was moderate-to-high confidence in the evidence showing exercise can improve cardiorespiratory fitness, power output, muscle strength, body composition, and cardiovascular risk factors (tables 2 and e-15). The only limitation revealed by the GRADE assessment was indirectness caused by the absence of participants aged over 65 y (table 2). There was very low confidence in the evidence for bone health (tables 2 and e-15).

There was low-to-moderate confidence in the evidence showing that 2-3 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-40 min, plus upper-body strength exercise (3 sets of 10 repetitions at 50-80% 1RM for all large muscle groups), can improve cardiorespiratory fitness, power output and muscle strength (tables 3, e-10 and e-16). There was low-to-moderate confidence in the evidence showing that 3-5 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-44 min can improve cardiorespiratory fitness, muscle strength, body composition, and cardiovascular risk (tables 4, e-11 and e-17). The lack of sufficient high-quality studies (table e-9) prohibited formulating guideline recommendations for the use of exercise types other than upper-body aerobic exercise and upper-body aerobic plus strength exercise.

Adverse events were described in 27 studies involving 368 participants (table e-13). The 99 participants who performed upper-body aerobic and/or strength exercise reported: no adverse events (n=93), muscle soreness (n=3), neck pain (n=1), or mild autonomic dysreflexia (n=1). Participants performing FES or ambulation exercise reported hip subluxation (n=1), or other adverse events such as lightheadedness or increased spasticity (approximately 10-20% of participants).

## DISCUSSION

This systematic review was undertaken to provide the evidence base for drafting guideline recommendations to inform an update of the 2011 SCI-exercise guidelines.[2]

### *Evidence regarding exercise for adults with acute SCI*

The review showed that no new Level 1 or 2 studies have been added to the evidence base in the last six years.[2, 18, 20, 21] Despite promising pre-clinical studies supporting beneficial effects on cardiometabolic health when lower-limb exercise starts acutely post-injury,[26] the current absence of high-quality, consistent evidence prohibits drafting exercise guideline recommendations for adults with acute SCI.

***Evidence regarding exercise for adults with chronic SCI***

Over the last six years, there has been an increase in high-quality studies demonstrating the beneficial effects of exercise on fitness and cardiometabolic health for adults with chronic SCI: across these outcomes, 10 out of the 12 Level 1 or 2 studies published in 2011-2016 demonstrated significant improvements in exercise versus control groups. These studies underpinned the moderate-to-high confidence in the evidence that exercise can improve all of the reviewed outcomes except bone health, for which confidence was very low. For younger and middle-aged adults with chronic SCI, confidence was high. The primary reason for downgrading confidence to “moderate” was that older adults were not represented. This is not surprising given that historically, SCI typically occurred during early adulthood, especially for SCI due to traumatic etiology.[27, 28]

There was sufficient evidence to formulate two guideline recommendations; one for upper-body aerobic *plus* strength-exercise, and another for upper-body aerobic exercise alone. The aerobic plus strength-exercise recommendation had evidence for effects on all fitness outcomes for young and middle-aged adults with AIS A-D, but not for older adults (table 5). The aerobic-exercise alone recommendation had evidence supporting its effects on two of the three fitness outcomes and both cardiometabolic health outcomes, but the evidence did not include older adults and/or people with AIS C or D injuries (table 5). The limited adverse event data for upper-body aerobic and/or strength exercise suggests that adverse events are rare, except for the occasional occurrence of musculoskeletal complaints. Thus, it appears safe for adults with chronic SCI to use these exercise prescriptions.

The aerobic plus strength-exercise recommendation for improving fitness aligns with the 2011 guidelines,[2] and is supported by a Level 1 study demonstrating fitness significantly improves when this guideline is implemented.[29] In contrast, the aerobic-exercise alone recommendation for improving fitness indicates more frequent and longer aerobic exercise sessions are required when strength exercise is not part of the prescription. Presumably, upper-body strength exercise provides an additive stimulus for cardiorespiratory and muscle strength adaptations associated with upper-body aerobic exercise,[30, 31] so less aerobic exercise is needed when strength exercise is part of the prescription. The aerobic-exercise alone recommendation for achieving health benefits is also more frequent and longer than the recommendation for achieving fitness benefits. It seems a greater aerobic stimulus is needed to acquire chronic adaptations in cardiovascular structure and function, modify cardiovascular disease risk factors, and elicit body composition changes.[13, 32, 33]

Interestingly, both recommendations include considerably less aerobic exercise than the WHO guidelines for the general population, i.e., 150 min/week of moderate physical activity or 75 min/week of vigorous physical activity,[12] which were derived from evidence regarding the dose-response relationship between exercise and other forms of physical activity (e.g., sports, activities of daily living), fitness and health in non-SCI populations.[34-41] Whereas the guideline recommendations derived from this review represent *minimum* amounts of exercise, the WHO guidelines likely reflect *optimal* amounts.[13] Indeed, healthy able-bodied people, especially if starting from a sedentary state, have been shown to accrue health benefits when exercising at levels similar to the levels recommended in this review.[13, 41]

### *Limitations of the evidence base*

Several limitations of the evidence base identified in this review represent issues to be addressed in future research (table 6). First, despite tremendous ethical and practical challenges of conducting high quality, adequately-powered studies in people with acute SCI,[42, 43] RCTs are needed to control for deteriorations in fitness and health that typically occur in the first months post-injury.[44, 45] These deteriorations could mask the effects of exercise for this population. Second, older adults were not represented in the evidence base whatsoever, and adults with incomplete motor lesions were not included in studies used to formulate the aerobic-exercise alone recommendations for cardiometabolic health improvements (table 5). Given increases in these segments of the SCI population,[27, 28] research is urgently needed to test the efficacy of the guideline recommendations in these sub-groups.[46] Third, very few of the studies on FES and ambulation exercise were high-quality studies with a non-exercising control group. Consequently, despite the positive effects shown in some of these studies, guideline recommendations could not be formulated for the use of these clinically popular exercise types. Fourth, despite including keywords such as "physical activity" and "sports", no studies were found that employed forms of physical activity other than exercise as an intervention, while describing frequency, intensity and/or duration of physical activity. Whether the conclusions and recommendations can be generalized to other forms of physical activity remains to be determined. Finally, there was a near-absence of studies comparing different exercise prescriptions relative to control groups. Such studies would improve confidence in drawing conclusions about the effectiveness of one exercise prescription versus another.

The relatively poor scores on the risk of bias assessments highlight a need to apply standard study reporting criteria for describing randomization procedures, exercise intervention protocols, control conditions, dropout rates and incidence of adverse events.[47-49] Application of a common set of standardized outcome measures would facilitate comparisons across studies. Also, the dose-response relationship between exercise, health, and fitness could be examined if changes in participants' exercise behaviour were tracked and recorded.

***Limitations of the review***

One limitation is that vote counting of statistically significant results was used to synthesize the studies. Although this strategy is not ideal,[50] alternative approaches were not possible.[51] Without established benchmarks[52] indicating what constitutes a clinically meaningful improvement in each outcome measure, and in each SCI sub-group (e.g., paraplegia, tetraplegia), a synthesis or conclusions based on clinical significance is impossible. Moreover, few studies reported effect sizes or sufficient data to calculate effect sizes, thus precluding a meta-analysis (e.g., see tables e-18 and e-19 for the data reported in studies used to draft the guideline recommendations and their effect sizes). Although vote-counting significant results based on small samples can increase the risk of Type II errors, and comparisons of multiple measures of the same outcome can increase family-wise error rates, nearly all studies showed improvements in all outcomes, except bone health. Likewise, although there were not enough sufficiently powered studies or total number of participants across all studies to have high confidence in the guideline recommendations, significant improvements were found in nearly all studies using these prescriptions. Such consistent patterns bolster confidence in our conclusions regarding the effects of exercise and the guideline recommendations.

Another limitation is that because the review was undertaken to inform guidelines, the set of reviewed outcomes was limited to those with sufficient high-quality studies to draft guideline recommendations. Exercise may have significant positive effects on other valued outcomes (e.g., psychological well-being, pain, quality of life) not included in this review.

***Strengths of the review***

The systematic approach to appraising exercise prescription evidence, based on internationally endorsed methods,[10, 24, 50] resulted in the drafting of guideline recommendations firmly rooted in the best available science. The inclusion of studies involving participants with varying baseline levels of exercise participation increases the generalizability and robustness of the conclusions and recommendations. Finally, an important contribution is the drafting of guideline recommendations to improve cardiometabolic health. Only six years ago, there was insufficient SCI-specific evidence to support such recommendations.[11]

### *Implications*

A robust and growing body of evidence shows that exercise improves fitness and cardiometabolic health of adults with chronic SCI. Our review of this evidence can now be used to inform development of SCI-specific exercise guidelines, through a systematic process involving deliberation and engagement with key stakeholders.[11] Nevertheless, significant gaps in knowledge remain, as the quality and size of the SCI evidence-base lags far behind the evidence-base for the general population. A challenge for researchers is to conduct high-quality studies that can advance the SCI evidence-base to the point where guidelines can be developed for all adults with SCI, for a range of fitness and health outcomes, and with a high level of confidence.

**Table 1** GRADE assessments[24, 25] and conclusion statements for the evidence regarding the effects of exercise on each of the reviewed outcomes of adults with acute SCI.

| **Outcome**[a] | **GRADE assessment**[b] | **GRADE confidence rating** | **Conclusion statement**[c] |
|---|---|---|---|
| Cardiorespiratory fitness | Very serious risk of bias (no Level 1 or 2 studies), Imprecision (N=290 and no studies providing a power calculation), and Indirectness (older adults >65 y not represented in the averaged age range) | Very low | Very low confidence in the evidence showing that exercise can improve cardiorespiratory fitness of adults with acute SCI. |
| Power output | Very serious risk of bias (no Level 1 or 2 studies), Inconsistency (only 5 out of 9 Level 3 or 4 studies showed improvements, while Level 1 or 2 studies were absent), and Indirectness (older adults >65 y not represented in the averaged age range) | Very low | Very low confidence in the evidence showing that exercise can improve power output of adults with acute SCI. |
| Muscle strength | Serious risk of bias (only 1 Level 1 and no Level 2 studies), Inconsistency (improvements shown in only 2 out of 6 Level 3 or 4 studies, while the Level 1 study provided inconclusive results), and Indirectness (adults with thoracic or lumbar lesions not represented) | Very low | Very low confidence in the evidence showing that exercise can improve muscle strength of adults with acute SCI. |
| Body composition | Inconsistency (improvements shown in only 1 out of the 2 Level 2 studies and only 1 out of the 2 Level 4 studies), Imprecision (N=67 and no studies providing a power calculation), and Indirectness (older adults >65 y not | Very low | Very low confidence in the evidence showing that exercise can improve body composition |

| | | | |
|---|---|---|---|
| | represented in the averaged age range) | | of adults with acute SCI. |
| Cardiovascular risk | Very serious risk of bias (no Level 1 or 2 studies), Inconsistency (only 2 out of the 3 Level 4 studies showed improvements, while Level 1 or 2 studies were absent), Imprecision (N=34 and no studies providing a power calculation), and Indirectness (older adults >65 y not represented in the averaged age range) | Very low | Very low confidence in the evidence showing that exercise can improve cardiovascular risk of adults with acute SCI. |
| Bone health | Serious risk of bias (only 1 Level 1 and no Level 2 studies), Inconsistency (improvements shown in only 2 out of the 3 Level 3 studies, while the Level 1 study showed no improvements), Imprecision (N=74 and no studies providing a power calculation), and Indirectness (older adults >65 y not represented in the averaged age range) | Very low | Very low confidence in the evidence showing that exercise can improve bone health of adults with acute SCI. |

[a]Outcome measures in each outcome are defined in table e-3.

[b]Only shown are reasons for decreasing the confidence rating in the evidence. See table e-8 for GRADE criteria and table e-6 for evidence summary.

[c]See table e-14 for full narrative descriptions of rationale for the conclusion statements.

Abbreviations: GRADE = Grading of Recommendations, Assessment, Development, and Evaluation; SCI = spinal cord injury

**Table 2** GRADE assessments[24, 25] and conclusion statements for the evidence regarding the effects of exercise on each of the reviewed outcomes of adults with chronic SCI.

| **Outcome**[a] | **GRADE assessment**[b] | **GRADE confidence rating** | **Conclusion statement**[c] |
|---|---|---|---|
| Cardiorespiratory fitness | Indirectness (older adults >65 y not represented in the averaged age range) | Moderate | Moderate confidence in the evidence showing that exercise can improve cardiovascular fitness of *any* adult with chronic SCI.<br>High confidence in the evidence showing that exercise can improve cardiorespiratory fitness of *young and middle-aged adults* with chronic SCI. |
| Power output | Indirectness (older adults >65 y not represented in the averaged age range) | Moderate | Moderate confidence in the evidence showing that exercise can improve power output of *any* adult with chronic SCI.<br>High confidence in the evidence showing that exercise can improve power output of *young and middle-aged adults* with chronic SCI. |
| Muscle strength | Indirectness (older adults >65 y not represented in the averaged age range) | Moderate | Moderate confidence in the evidence showing that exercise can improve muscle strength of *any* adult with chronic SCI.<br>High confidence in the evidence showing that exercise can improve muscle strength of *young and middle-aged adults* with chronic SCI. |
| Body composition | Indirectness (older adults >65 y not represented in the averaged age range) | Moderate | Moderate confidence in the evidence showing that exercise can improve body composition of *any* adult with chronic SCI. |

| | | | |
|---|---|---|---|
| | | | High confidence in the evidence showing that exercise can improve body composition of *young and middle-aged adults* with chronic SCI. |
| Cardiovascular risk | Indirectness (older adults >65 y not represented in the averaged age range) | Moderate | Moderate confidence in the evidence showing that exercise can improve cardiovascular risk of *any* adult with chronic SCI.<br>High confidence in the evidence showing that exercise can improve cardiovascular risk of *young and middle-aged adults* with chronic SCI. |
| Bone health | Very serious risk of bias (no Level 1 or 2 studies), Inconsistency (only 8 out of 22 Level 1 or 2 studies showed improvements; Level 1 or 2 studies were absent), Imprecision (N=334 and no studies providing a power calculation), and Indirectness (studies did not include participants with AIS D, while older adults >65 y were not represented in the averaged age range) | Very low | Very low confidence in the evidence showing that exercise can improve bone health of adults with chronic SCI. |

[a]Outcome measures representing each outcome are defined in table e-3.

[b]Only shown are reasons for decreasing the confidence rating in the body of evidence. See table e-8 for the GRADE criteria and table e-7 for the evidence summary.

[c]See table e-15 for full narrative descriptions of rationale for the conclusion statements.

Abbreviations: AIS = American Spinal Injury Association Impairment Scale; GRADE = Grading of Recommendations, Assessment, Development, and Evaluation; SCI = spinal cord injury

**Table 3** GRADE assessments[24, 25] and conclusion statements for the evidence regarding the effects of combined upper-body aerobic plus strength exercise on each of the reviewed outcomes of adults with chronic SCI.

| **Outcome**[a] | **GRADE assessment**[b] | **GRADE confidence rating** | **Conclusion statement**[c] |
|---|---|---|---|
| Cardiorespiratory fitness | Indirectness (older adults >65 y not represented in the averaged age range), and Imprecision (N=129 and no studies providing a power calculation) | Low | Low confidence in the evidence showing that 2-3 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-30 min combined with upper-body strength exercise (3 sets of 50-80% 1RM for all large muscle groups) can improve cardiovascular fitness of *any* adult with chronic SCI.<br>Moderate confidence in the evidence showing that this exercise prescription can improve cardiorespiratory fitness of *young and middle-aged adults* with chronic SCI. |
| Power output | Indirectness (older adults >65 y not represented in the averaged age range), and Imprecision (N=147 and no studies providing a power calculation) | Low | Low confidence in the evidence showing that 2 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-40 min combined with upper-body strength exercise (3 sets of 50-80% 1RM for all large muscle groups) can improve power output of *any* adult with chronic SCI.<br>Moderate confidence in the evidence showing that this exercise prescription can improve power output of *young and middle-aged adults* with chronic SCI. |
| Muscle | Indirectness (older adults >65 y not | Low | Low confidence in the evidence showing that 2 sessions per week of upper-body |

| | | | |
|---|---|---|---|
| strength | represented in the averaged age range), and Imprecision (N=119 and no studies providing a power calculation) | | aerobic exercise at a moderate-to-vigorous intensity for 20-40 min combined with upper-body strength exercise (3 sets of 50-80% 1RM for all large muscle groups) can improve muscle strength of *any* adult with chronic SCI.<br>Moderate confidence in the evidence showing that this exercise prescription can improve muscle strength of *young and middle-aged adults* with chronic SCI. |

[a]No or only one Level 1 or 2 study was available for the effects of combined upper-body aerobic exercise and strength exercise on cardiovascular risk or bone health of adults with chronic SCI. These outcome types were not included in the evidence summaries. Outcome measures representing each outcome are defined in table e-3.

[b]Only shown are reasons for decreasing the confidence rating in the body of evidence. See table e-8 for the GRADE criteria and table e-10 for the evidence summary.

[c]This statement was based on the prescription of the Level 1 and 2 studies that showed significant improvements. An exception was made for the prescription regarding the effects of upper-body aerobic plus strength exercise on cardiorespiratory fitness. See table e-16 for full narrative descriptions of rationale for the conclusion statements. Abbreviations: AIS = American Spinal Injury Association Impairment Scale; GRADE = Grading of Recommendations, Assessment, Development, and Evaluation; SCI = spinal cord injury.

**Table 4** GRADE assessments[24, 25] and conclusion statements for the evidence regarding the effects of upper-body aerobic exercise on each of the evaluated outcomes of adults with chronic SCI.

| **Outcome**[a] | **GRADE assessment**[b] | **GRADE confidence rating** | **Conclusion statement**[c] |
|---|---|---|---|
| Cardiorespiratory fitness | Indirectness (older adults >65 y not represented in the averaged age range and AIS C-D not represented and/or AIS levels not reported), and Imprecision (N=237 and no studies providing a power calculation) | Low | Low confidence in the evidence showing that 3-5 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 20-44 min can improve cardiorespiratory fitness of *any* adult with chronic SCI.<br>Moderate confidence in the evidence showing that this exercise prescription can improve cardiorespiratory fitness of *young and middle-aged adults* with chronic SCI. |
| Muscle strength | Indirectness (older adults >65 y not represented in the averaged age range), and Imprecision (N=137 and no studies providing a power calculation) | Low | Low confidence in the evidence showing that 3 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 30-44 min can improve muscle strength of *any* adult with chronic SCI.<br>Moderate confidence in the evidence showing that this exercise prescription can improve muscle strength of *young and middle-aged adults* with chronic SCI. |
| Body composition | Indirectness (older adults >65 y not represented in the averaged age range and AIS D not represented and/or AIS levels | Low | Low confidence in the evidence showing that 3-5 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 30-44 min can improve body composition of *any* adult with chronic SCI. |

| | | | |
|---|---|---|---|
| | not reported), and Imprecision (N=88 and no studies providing a power calculation) | | Moderate confidence in the evidence showing that this exercise prescription can improve body composition *young and middle-aged adults* with chronic SCI at AIS A-C lesion completeness levels. |
| Cardiovascular risk | Indirectness (older adults >65 y not represented in the averaged age range and AIS C-D not represented and/or AIS levels not reported), and Imprecision (N=91 and no studies providing a power calculation) | Low | Low confidence in the evidence showing that 3 sessions per week of upper-body aerobic exercise at a moderate-to-vigorous intensity for 30-44 min can improve cardiovascular risk of *any* adult with chronic SCI.<br>Moderate confidence in the evidence showing that this exercise prescription can improve cardiovascular risk of *young and middle-aged adults* with chronic SCI at AIS A-B lesion completeness levels. |

[a]No or only one Level 1 or 2 study was available for the effects of upper-body aerobic exercise on power output and bone health of adults with chronic SCI (see table e-9); these outcomes were not included in the GRADE assessments. Outcome measures representing each outcome are defined in table e-3.

[b]Only shown are reasons for decreasing the confidence rating in the body of evidence. See table e-8 for the GRADE criteria and table e-11 for the evidence summary.

[c]This statement was based on the prescription of the Level 1 and 2 studies that showed significant improvements. See table e-17 for full narrative descriptions of rationale for the conclusion statements.

**Table 5.** GRADE confidence ratings[10, 24] for the evidence used to formulate the guideline recommendations.

| | **Combined upper-body aerobic plus strength exercise**[a] | | **Upper-body aerobic exercise**[b] | | |
|---|---|---|---|---|---|
| **Outcome**[3] | Adults of any age with chronic SCI and AIS A-D | Young and middle-aged adults with chronic SCI and AIS A-D | Adults of any age with chronic SCI and AIS A-D | Young and middle-aged adults with chronic SCI and AIS A-B | Young and middle-aged adults with chronic SCI and AIS C-D |
| **Fitness** | | | | | |
| Cardiorespiratory fitness | Low | Moderate | Low | Moderate | Low |
| Power output | Low | Moderate | Insufficient evidence[c] | Insufficient evidence[c] | Insufficient evidence[c] |
| Muscle strength | Low | Moderate | Low | Moderate | Moderate |
| **Cardiometabolic health** | | | | | |
| Body composition | Insufficient evidence[c] | Insufficient evidence[c] | Low | Moderate | Low |
| Cardiovascular risk | Insufficient evidence[c] | Insufficient evidence[c] | Low | Moderate | Low |

[a]2-3 sessions per week of moderate to vigorous intensity upper-body aerobic exercise for 20-30 min combined with upper-body strength exercise (3 sets of 10 repetitions, at 50-80% 1RM for all large muscle groups)

**[b]**3-5 sessions per week of moderate to vigorous intensity upper-body aerobic exercise for 20-44 min (cardiorespiratory fitness) or 30-44 min (muscle strength, body composition and cardiovascular risk)

[c]GRADE ratings only reported for outcomes with sufficient high quality studies to formulate a guideline recommendation,[25] i.e. at least two high quality studies (table e-9).

Abbreviations: AIS = American Spinal Injury Association Impairment Scale; GRADE = Grading of Recommendations, Assessment, Development, and Evaluation; SCI = spinal cord injury.

**Table 6.** Recommendations for future research, based on the limitations of the evidence base identified in this review.

| |
|---|
| **To further increase confidence in the evidence for the guideline recommendations emerging from this review, there is a need for controlled, sufficiently-powered studies using standardized reporting criteria regarding the effects of:** |
| • combined upper-body aerobic plus strength exercise (prescription in accordance with recommendations of our review) on fitness of older adults with chronic SCI<br>• upper-body aerobic exercise (prescription in accordance with recommendations of our review) on body composition of adults of any age with chronic SCI and AIS D<br>• upper-body aerobic exercise (prescription in accordance with recommendations of our review) on cardiovascular risk of adults of any age with chronic SCI and AIS C or D |
| **Due to a lack of sufficient high-quality studies, guideline recommendations in this review were limited to adults with chronic SCI, specific exercise types, and fitness and cardiometabolic health. This attests to the need for controlled, sufficiently-powered studies using standardized reporting criteria regarding the effects of:** |
| • exercise on fitness, cardiometabolic health and/or bone health of adults of any age with acute SCI<br>• exercise on bone health of adults of any age with chronic SCI<br>• exercise types other than combined upper-body aerobic plus strength exercise and upper-body aerobic exercise (e.g. FES, ambulation, upper-body strength exercise) on fitness, cardiometabolic health and/or bone health of adults of any age with chronic SCI<br>• forms of physical activity other than exercise on fitness, cardiometabolic health or bone health of adults of any age with acute or chronic SCI, while describing frequency, intensity and/or duration of physical activity |

Abbreviations: AIS = American Spinal Injury Association Impairment Scale; FES = functional electrical stimulation; SCI = spinal cord injury

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