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# The effects of upper body exercise on the physical capacity of people with a spinal cord injury: a systematic review

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**Objective**: To describe the effects of upper body training on the physical capacity of people with a spinal cord injury.
**Data sources**: The databases of PubMed, CINAHL, Sport Discus and Cochrane were searched from 1970 to May 2006.
**Review methods**: The keywords ‘spinal cord injury’, ‘paraplegia’, ‘tetraplegia’ and ‘quadriplegia’ were used in combination with ‘training’. The methodological quality of the included articles (both randomized controlled trials and controlled clinical trials) was assessed with the modified ‘van Tulder *et al.*’ checklist. Studies were described with respect to population, test design, training protocol and mode of training. The training effects on physical capacity, reflected by peak power output ($PO_{peak}$) and oxygen uptake ($\dot{V}O_{2peak}$), were summarized.
**Results**: Twenty-five studies were included with a mean score of 8.8 out of 17 items on the quality checklist. The methodological quality was quite low, mostly because of the absence of randomized controlled trials. Therefore no meta-analysis was possible. In the 14 articles of acceptable quality the mean (SD) increase in $\dot{V}O_{2peak}$ and $PO_{peak,}$ following a period of training, was 17.6 (11.2)% and 26.1 (15.6)%, respectively.
**Conclusions**: Due to the overall low quality of studies it is not possible to draw definitive conclusions on training effects for different lesion groups or training modes. The results of the relatively few studies with an acceptable quality seem to support the view that upper body exercise may increase the physical capacity of people with spinal cord injury. The magnitude of improvement in $PO_{peak}$ and $\dot{V}O_{2peak}$, however, varies considerably among studies.

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## Introduction

As a result of a spinal cord injury, the somatic and autonomic nervous system is damaged. The most serious consequence is paralysis of muscles below the level of the lesion, depending in severity on the completeness and level of lesion. Secondary complications may occur as a consequence of spinal cord injury, such as urinary tract infections, spasticity, hypotension, autonomic dysreflexia, pressure sores, arm overuse injuries, fractures, venous thrombosis and respiratory infections.[1] Moreover, having lost a considerable part of the functioning of their (lower) body, often leading to a wheelchair-dependent life, it is difficult for those with spinal cord injury to maintain an active lifestyle. As a consequence of the spinal cord injury, the secondary complications and the sedentary lifestyle of people with spinal cord injury, deconditioning is likely to occur with increased risk of obesity, diabetes and cardiovascular diseases.[2,3] Deconditioning in turn results in a lower physical capacity. Therefore people with such injuries, especially those with tetraplegia, will have difficulty in coping with the strain of daily activities.[4,5] People with spinal cord injury who are not able to participate in daily activities appear to be more handicapped (e.g. in the domains of physical independence and mobility) and tend to give lower ratings for quality of life.[6–8]

To cope adequately with the strain of daily activities and to prevent long-term secondary health problems, it is important to have and maintain an optimum level of physical fitness. Physical fitness is often developed during initial rehabilitation[9] and must be maintained in a process of a long-term physically active lifestyle and/or rehabilitation aftercare. This requires an understanding – and the availability – of evidence-based training methods and exercise protocols for people with spinal cord injury. Although guidelines for upper body training in people with spinal cord injury have been published by several authors,[10–12] the experimental evidence base of these guidelines is unclear. Systematic reviews are lacking or outdated. In 1986, Hoffman[3] published a review study about upper body training in people with spinal cord injury. However, this review does not describe the methodological quality of the included studies and is already quite outdated.

The purpose of the current review is therefore to systematically summarize the effects of upper body training on physical capacity in people with spinal cord injury, while taking into account the methodological quality of the studies. Second, we will try to compare training effects on physical capacity between people with paraplegia and tetraplegia and between different modes of training.

Active and functional training of the physical capacity in wheelchair-dependent people with motor-complete spinal cord injury must primarily be acquired through upper body exercise. Therefore, despite the growing use of electrically stimulated lower limb exercise and body weight support treadmill walking, the scope of this study was on training of physical capacity of the upper body. Upper body training is usually performed with exercise in a wheelchair (on a treadmill) or on a wheelchair ergometer, or with the use of arm crank exercise.[13] Recently, however, other upper body training modes such as circuit resistance training and hand cycling have been used as well.

The two most important components of physical capacity are peak oxygen uptake and power output.[9] Muscle strength, cardiovascular and respiratory function are components that contribute to the level of oxygen uptake and power output.[9] In the current study, peak oxygen uptake and peak external power output are studied as the prime outcome parameters of upper body training exercise in spinal cord injury.

The main research question of this study is, therefore: What are the effects of different modes of upper body training on physical capacity, reflected by peak oxygen uptake and power output, in people with paraplegia or tetraplegia?

## Methods

### Study identification and selection

The electronic databases of PubMed (MEDLINE), Sport Discus, CINAHL and Cochrane were systematically searched with the following (combinations of) keywords: ‘spinal cord injury’, ‘paraplegia’, ‘tetraplegia’ and ‘quadriplegia’, combined with ‘training’. The search was limited to the English language and included publications from 1970 up to May 2006. After this first selection of studies, all hits were investigated more thoroughly. Of all included articles, we scanned the references for more hits. To be included in this review, studies had to meet the following inclusion criteria:

1) The research population is described properly, and no more than 25% of the subjects have an impairment other than spinal cord injury.
2) The upper extremities are trained.
3) No functional electrical stimulation is part of the training protocol, meaning that at least in one of the experimental groups isolated upper body training is performed.
4) The training protocol is described explicitly.
5) One or both of the main components of physical capacity peak oxygen uptake ($\dot{V}O_{2peak}$) or peak power output ($PO_{peak}$) are outcome measures of the study.

### Qualitative assessment

The methodological quality was assessed using the 19-item list of Van Tulder *et al.*[14] This quality assessment list is designed to score the methodological quality of randomized controlled trials (RCTs). However non-randomized clinical trials might be included if the available evidence for RCTs is not sufficient.[14] We discussed the available RCTs separately and scored the methodological quality of all available articles, which met our inclusion criteria.

Blinding of the assessor (item i) was regarded to be a relevant item, but blinding of the trainer (item e) or blinding of the patient (item h) was considered to be not relevant when comparing a training group with a group receiving no training at all. The total number of items that were scored was thus reduced to 17. The quality score was based on the mean score of two independent observers (LV and ET) who used a consensus method to discuss and resolve any disagreements.

We considered the studies with a score of more than 50% (9 or more of the 17 items are scored positive) to be of an 'acceptable methodological quality' and studies with less than 9 will be considered to have a 'low methodological quality'. Van Tulder *et al.*[14] suggested a quality cut-off point of 50% but this was chosen arbitrarily.

### Quantitative analysis

To provide an overview of the actual effects of training of the upper body on physical capacity, the percentage change in $PO_{peak}$ and $\dot{V}O_{2peak}$ will be described. Only the effects on physical capacity of the studies with an acceptable methodological quality will be discussed further.

## Results

After searching the different databases, and following screening of titles and abstracts for consistency with inclusion criteria, 40 papers were identified as potentially relevant (Figure 1). After reading the 40 papers (LV: PhD student and ET: MSc in Human Movement Science; both experienced in physical therapy research methods), 15 training studies were excluded for the following reasons: other outcome measures,[15–23] mixed population,[24,25] the population was not described properly,[26] training of both arms and legs[27] or – as was the case in two papers – the results were already published in other included papers.[28,29] The 25 included studies are summarized in Table 1.[30–54]

### Qualitative assessment

Only two out of 25 studies appeared to be relevant RCTs, investigating the effect of training versus no training in people with spinal cord injury.[31,32] Both studies were of an acceptable, but still rather low, quality score of respectively 9.5 and 10.5. Only one of two other studies comparing two groups training on different intensities[42,52] used randomization.[52] One RCT, with a relatively high quality score of 12.5, was designed to study effects of two different training positions (supine versus sitting).[35] One of the studies compared training in an untrained group with 'no training at all' in sedentary controls, but without randomization.[49] The remaining studies compared conditioning effects before and after training without a control group.

In five out of 25 articles disagreement between the observers existed on more than two items in one paper. Scores were averaged if no consensus was reached and ranged from 6 to 12.5 and the mean score of all papers was 8.8 ± 0.7 (meanSD). The methodological quality was acceptable according to our arbitrary standard (i.e. $\geqslant$50%) in 14 studies, while 11 studies had a low methodological quality scoring less than 9 points (Tables 1a, b and c).

Other factors that influenced the quality of research were noted. Blinding of the assessor was not described in the available RCTs.[31,32,35] Compliance was described sufficiently in 10 studies.[30,31,35,37,41,42,44,50,52] Drop-out rate was not described in eight studies.[36,39,43,47,48,51,53,54] In all other studies the drop-out rate was described and

Search terms:

| | | | |
|---|---|---|---|
| Spinal cord injury | and | Training: | 972 |
| Tetraplegia | | Training | + 138 (new found papers) |
| Quadriplegia | | Training | + 2 (new found papers) |
| Paraplegia | | Training | + 197 (new found papers) |
| Total | | | 1309 |

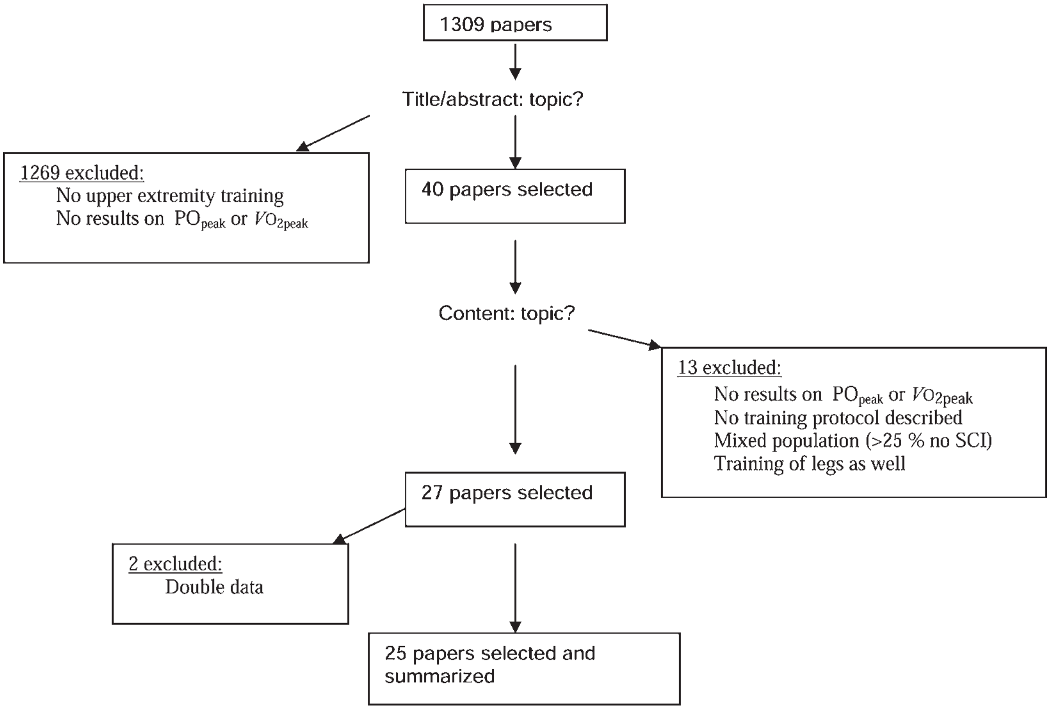

**Figure 1** Flowchart for the systematic search and selection of papers.

found to be acceptable, with the exception of the subjects performing the long-term training programme in the study of Davis *et al.*,[31] where the cut-off point of 30% was exceeded. 'Adverse effects' were described explicitly in 10 studies, but in general the training was well tolerated.[30,31,35,37–39,44,45,49,50] Overall the lesion level was described, however not always the completeness of the lesion, described by the American Spinal Injury Association – Impairment Scale[55] or the previously used Frankel Scale. Finally, training status was not always mentioned in the reviewed studies and its description differed between studies.

## Description of the studies

### *Subject characteristics*

Table 1 summarizes all 25 included studies. Study populations differed considerably in size and composition. The number of subjects per study ranged between 1 and 20 with a mean value of almost 10 subjects per study. With the exception of the study by Gass *et al.*,[41] hardly any subjects with a Th1–Th5 lesion were enrolled and most studies on subjects with paraplegia included only subjects with lesions below Th6.[30–32,37–39,45,47,48] Six studies included subjects with a time since injury less than one year.[39,44,48,51,52,54]

**Table 1a** Studies on the effects of arm crank exercise

| Study | Score | TSI (years) | Training status | Mean age (years) | Sex | ASIA-IS | Lesion-level | Sample size | Control group | Training mode | Training protocol | Training intensity | Physical capacity outcomes | Other outcomes | Test device | Test protocol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACE: PARA** | | | | | | | | | | | | | | | | |
| 1 El Sayed 2005[30] | 9.5 | Unclear | No organized training | 31 | m,f | ? | <Th10 | 5 | No; 7 AB also training | con | 30 min/ session; 3/wk for 12 wks | 60–65% $VO_{2\text{peak}}$ | $PO_{\text{peak}}$<br>$VO_{2\text{peak}}$ | Peak HR,VE and chol | ACE | con: start: 30 W; 2 min + 30 W |
| 2 Davis 1991[31] | 9.5 | >5 | Inactive | 31 | m | ? | L5-Th6 | 6HL,<br>4HS,<br>5LL,<br>3LS, 6C | Yes; 6 RA non-training SCI | con | 40 min/ session; 3/wk for 32 wks | 50 or 70% $VO_{2\text{peak}}$ | $VO_{2\text{peak}}$ | MS, SV, PT, submax PO | ACE | con: start:?; 1 min + 8.5 W |
| 3 Taylor 1986[32] | 10.5 | >1 | Trained; basketball | 30 | m,f | ? | L5-Th6 | 5 | Yes; 5 RA non-training SCI | con | 30 min/ session; 5/wk for 8 wks | 80% $HR_{\text{peak}}$ | $VO_{2\text{peak}}$ | Peak and rest HR, BM, PF MFD | ACE | con: ; start: ? 4 min + 10 W |
| **ACE: TETRA** | | | | | | | | | | | | | | | | |
| 4 DiCarlo 1982[33] | 8.5 | >3 | No aerobic training | 24 | m | ? | C6 | 1 | No | con | 30 min/ session; 3/wk for 8 wks | HR = 96 | $PO_{\text{peak}}$<br>$VO_{2\text{peak}}$ | BM, peak HR and VE, submax PO, HR, VE and $VO_2$ | ACE | ?: 2 min + 10 rpm |
| 5 DiCarlo 1988[34] | 7 | 2–21 | No aerobic training last 6 months | 24 | ? | ? | C7-C5 | 8 | No | ? | 15/30 min/ session; 3/wk for 8 wks | 50–60% HRR | $PO_{\text{peak}}$<br>$VO_{2\text{peak}}$ | 12 min test, BM, peak HR, VE; submax PO, HR, VE and $VO_2$ | ACE | start ?: 2 min + 10 rpm |
| 6 McLean 1995[35] | 12.5 | >2 | No aerobic training last 6 months | 34 | m | ? | Th1-C5 | sit: 7;<br>sup: 7 | Yes; same intensity both groups; RA | con | 20 + min/wk; 3/wk for 10 wks | 60% $PO_{\text{peak}}$ | $PO_{\text{peak}}$<br>$VO_{2\text{peak}}$ | Peak and rest HR, BM, SV, PT | ACE | int: start: ?; 3 min 40 s + 10 W, rest: 1 min 20 s |
| **ACE: COMBI** | | | | | | | | | | | | | | | | |
| 7 DiCarlo 1983[36] | 8 | ? | No aerobic training last 6 months | 25 | m | ? | Th8-C5 | 4 | No | int | 37 min/ session; 3/wk for 5 wks | 60–80% $HR_{\text{peak}}$ | $PO_{\text{peak}}$<br>$VO_{2\text{peak}}$ | n/a | ACE | int: start: 5 W; 3 min + 20 rpm; rest: 1 min |

ACE, arm crank exercise; PARA, paraplegia; TETRA, tetraplegia; COMBI, paraplegia and tetraplegia; ASIA-IS, American Spinal Injury Association Impairment Scale (grades A; B, C, D or E); RA, randomly allocated; HL, high intensity – long duration; HS, high intensity – short duration; LL, low intensity – long duration; LS, low intensity – short duration; AB, able bodied; C, controls; CRT, circuit resistance training; int, interval; con, continuous; HR, heart rate; HRR, heart rate reserve; WC-skills, wheelchair skills; BM, body mass; chol, cholesterol; PT, performance time; MS, muscle strength; BP, blood pressure; VE, ventilation; PF, pulmonary function; ADL, activities of daily living; SV, stroke volume; LA, lactate; VT, ventilatory threshold; rpm, rate per minute; W, watts.

**Table 1b** Studies on the effects of wheelchair exercise

| Study | Score | TSI (years) | Training status | Mean age (years) | Sex | ASIA-IS | Lesion-level | Sample size | Control group | Training mode | Training protocol | Training intensity | Physical capacity outcomes | Other outcomes | Test device | Test protocol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WCE: PARA** | | | | | | | | | | | | | | | | |
| 8 Bougenot 2003[37] | 10 | >1 | Physically active, no specific arm training | 35 | m | A | L5-Th6 | 7 | No | int | 45 min/session; 3/wk for 6 wks | Until 80% $HR_{peak}$ | $Vo_{2peak}$<br>$PO_{peak}$ | $HR_{peak}$ and VE, $O_2P$ and at VT | WCE | con: start: 15 W; 2 min + 10 W |
| 9 Tordi 2001[38] | 10 | >1 | Unclear | 27 | m | A | L4-Th6 | 5 | No | int | 30 min/session; 3/wk for 4 wks | 50–80% $PO_{peak}$ | $Vo_{2peak}$<br>$PO_{peak}$ | Submax PO, HR, VE and $Vo_2$, and $O_2P$, PT | WCE | con: start: 15 W; 2 min + 10 W |
| 10 le Foll-de-Moro 2005[39] | 8 | <1 | Rehab | 29 | m, f | ? | Th12-6 | 6 | No | int | 30 min/session; 3/wk for 6 wks | Until 80% $HR_{peak}$ | $Vo_{2peak}$<br>$PO_{peak}$ | $VE_{peak}$, submax PO, VE, $Vo_2$,PF | WCE | con: start: 15 W; 2 min + 5 W |
| **WCE: TETRA** | | | | | | | | | | | | | | | | |
| 11 Whiting 1983[40] | 7.5 | >3 | Untrained | 27 | m | ? | C7-C5 | 2 | No | con | 20 min/session; 7/wk for 8 wks | 75–85% $HR_{peak}$ | $Vo_{2peak}$<br>$PO_{peak}$ | $HR_{peak}$ | WCE | con: start: ?; 3 min + 5 W |
| **WCE: COMBI** | | | | | | | | | | | | | | | | |
| 12 Gass 1980[41] | 6.5 | >5 | Inactive | 37 | m, f | ? | Th4-C6 | 9 | No | con | Until exhaustion; 5/wk for 7 wks | Until exhaustion | $Vo_{2peak}$ | $HR_{peak}$ and VE; BM, PF | WCE | con: start: ?; 1 min + 0.5 km/h |
| 13 Hooker 1989[42] | | >29 | No training last year | 31 | m, f | ? | Th9-C5 | 6LI, 5MI | LI and MI; not RA | int | 20 min/session; 3/wk for 8 wks | 50–80% HRR | $Vo_{2peak}$<br>$PO_{peak}$ | Submax PO, HR and $Vo_2$, $HR_{peak}$,VE, LA, chol | WCE | int: start: 2 W; 3 min + 2 W up to 10 W |
| 14 Midha 1999[43] | 8 | >4 | ? | 36 | m, f | ? | L3-C6 | 12 (10SCI) | No | con | 22 min/session; 2 or 3/wk for 10 wks | 55–90% HR (220-age) | $Vo_{2peak}$<br>$PO_{peak}$ | Peak and rest HR, BM, BP, chol | WCE | con: ? |

WCE, wheelchair exercise; PARA, paraplegia; TETRA, tetraplegia; COMBI, paraplegia and tetraplegia; SCI, spinal cord injury; ASIA-IS, American Spinal Injury Association – Impairment Scale (grades A, B, C, D or E); RA, randomly allocated; LI, low intensity; MI, moderate intensity; CRT, circuit resistance training; int, interval; con, continuous; HR, heart rate; HRR, heart rate reserve; WC-skills, wheelchair skills; BM, body mass; chol, cholesterol; PT, performance time; MS, muscle strength; BP, blood pressure; VE, ventilation; $O_2P$, oxygen pulse; PF, pulmonary function; ADL, activities of daily living; SV, stroke volume; LA, lactate; VT, ventilatory threshold; W, watts.

**Table 1c** Studies on the effects of other training modes

| Study | Score | TSI (years) | Training status | Mean age (years) | Sex | ASIA-IS | Lesion-level | Sample size | Control group | Training mode | Training protocol | Training intensity | Physical capacity outcomes | Other outcomes | Test device | Test protocol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **OTHER: PARA** | | | | | | | | | | | | | | | | |
| 15 Duran 2000[44] | 9 | 8 < 1,<br>5 > 1 | Rehab | 26 | m, f | A,B,C | Th12-Th3 | 13 | no | WCE, weights, aerobic, HT | 120 min/session; 3/wk for 16 wks | 40–80% HRR | $PO_{peak}$ | $HR_{peak/recovery}$, WC-skills, BM, chol, MS | ACE | con: start: 0 W;<br>2 min + 12.5 W |
| 16 Jacobs 2001[45] | 9.5 | >0.7 | Unclear | 39 | m | A,B | L1-Th5 | 10 | no | CRT, int | 45 min/session; 3/wk for 12 wks | 50–80% (1RM) | $VO_{2peak}$<br>$PO_{peak}$ | PT, MS | ACE | con: start: 40 W;<br>3 min + 10 W |
| 17 Nash 2001[46] | 9.5 | >1 | Unclear | 38 | m | A | L1-Th6 | 5 | no | CRT, int | 45 min/session; 3/wk for 12 wks | 50–80% (1RM) | $VO_{2peak}$<br>$PO_{peak}$ | Chol | ACE | con: start: 40 W;<br>3 min + 10 W |
| 18 Rodgers 2001[47] | 6 | >7 | Unclear | 44 | m, f | ? | L5-Th3 | 19 (15SCI) | no | strength, rowing cont | ? min/session; 3/wk for 6 wks | 60% HRR rowing (30 min) | $VO_{2peak}$<br>$PO_{peak}$ | $HR_{peak}$, MS | WCE | con: start:?;<br>1 min + 0.3 kg load |
| 19 Sutbeyaz 2005 [48] | 8 | <1 | Rehab | 31 | m,f | A, BCD? | Th12-Th6 | 20 | no | ACE, Spiro-metry | Total 60 min:30 min ACE/3/wk/6 wks | 75–100% $VO_{2peak}$ | $VO_{2peak}$<br>$PO_{peak}$ and VE, BP, PF | Peak HR ACE | n/a | |
| **OTHER: TETRA** | | | | | | | | | | | | | | | | |
| 20 Dallm-eijer 1997[49] | 10.5 | >1 | Trained and untrained | 28 | m, f | A,B,C,D | C8-C4 | T: 9; U: 6 | yes; 9 *inactive* not RA | Quad Rugby; con | 90–120 min/session; 1/wk for 9–25 wks | 60 + % HRR | $VO_{2peak}$<br>$PO_{peak}$ | $HR_{peak}$, ADL, MS | ACE | con: start: 10% $PO_{peak}$;<br>1 min +10% $PO_{peak}$ |
| 21 Cooney 1986[50] | 9 | >2 | Unclear | 35 | m,f | ? | 5PP: L1-Th9; 5TP: C8-C5 | 10 | no | CRT | 30–40 min/session; 3/wk for 9 wks | 60–90% $HR_{peak}$ | $VO_{2peak}$<br>$PO_{peak}$ | Speed | ACE | int: start: 0 and 5 W;<br>3 min + 10 W, rest: 1 min |
| 22 Hjeltnes 1998[51] | 9 | <1 | Rehab | 25 | m | TP:A,B | C8-C6 | 10 PP<br>10 TP | no; 7 non training AB, tested once | ACE/WCE, strength | 30 + min/session; 3/wk for 2 × 8 wks | HI | $VO_{2peak}$<br>$PO_{peak}$ | $HR_{peak}$, submax PO, $VO_2$ and HR, BP, SV, LA, MS | ACE | int: 2 × 5 min submax., 3 min max intensity: ? |

(*Continued*)

**Table 1c** (*Continued*)

| Study | Score | TSI (years) | Training status | Mean age (years) | Sex | ASIA-IS | Lesion-level | Sample size | Control group | Training mode | Training protocol | Training intensity | Physical capacity outcomes | Other outcomes | Test device | Test proto-col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 De Groot 2003[52] | 12 | <1 | Rehab | 47 | m | A,B,C | L1-C5 | HI: 3<br>LI: 3 | yes:; HI and LI; RA. | ACE, CRT | 60 min/ session; 3/wk for 8 wks | 40–80% HRR | $Vo_{2peak}$<br>$PO_{peak}$ | chol | ACE | int: start: 16 W; 3 min + ?; rest: 2 min |
| 24 Nilsson 1975[53] | 7.5 | >1 | Trained | 36 | m | ? | PP: 5;<br>TP:2 | 7 | no; 5 not RA SCI tested once | ACE, CRT | ? min/ session; 3/wk for 7 wks | High | $Vo_{2peak}$<br>$PO_{peak}$ | peak HR, LA, MS | ACE | int: total duration max test: 4–6 min |
| 25 Knuttson 1973[54] | 6 | <1 | Rehab | ? | m,f | A or B | T5-C5:3<br>T6-L1:7 | 10 | no | ACE, CRT int | 30 min?/ 4a5/wk/ 6 wks | PP:140–180 bpm | $PO_{peak}$ | Blood volume, haemo-globine | ACE | start: 5–33 W 6 min +11–33 W until HR = 170 |

OTHER, all other modes of exercise; PARA or PP, paraplegia; TETRA or TP, tetraplegia; COMBI, paraplegia and tetraplegia; ASIA-IS, American Spinal Injury Association – Impairment Scale (grades A, B, C, D or E); RA, randomly allocated; RM, repetition maximum; HI, high intensity; LI, low intensity, CRT, circuit resistance training; int, interval; con, continuous; HR, heart rate; HRR, heart rate reserve; WC-skills, wheelchair skills; BM, body mass; chol, cholesterol; PT, performance time; MS, muscle strength; BP, blood pressure; VE, ventilation; PF, pulmonary function; ADL, activities of daily living; SV, stroke volume; LA, lactate; VT, ventilatorythreshold; W, watts.

### *Training mode and protocol*

As can be seen in Table 1, seven studies used arm crank exercise as the training mode, and seven studies used wheelchair exercise. The remaining 11 studies used another training mode (other), often combined with arm crank exercise.[45,48–51] Most often circuit resistance training or strength training was incorporated in these studies.[41–44,47–51]

The training intensities in the studies varied greatly, using different indicators for workload and ranging between 40 and 90% of the heart rate reserve (HRR), peak heart rate (HRpeak), $Vo_{2peak}$ or $PO_{peak}$. In all studies subjects trained three times a week or more, with the exception of Dallmeijer *et al.*[49] (only once a week). The duration of the training sessions varied from 20 to 120 min; in most studies the sessions lasted 30 min. The duration of the training period varied considerably (4–32 weeks).

## Training effects

### *Overall*

In Table 2 the pre- and post-training values for $Vo_{2peak}$ and $PO_{peak}$ and the relative change (expressed in percentage from the pre-training values) after training are listed. Eighteen of the 21 studies with data on $Vo_{2peak}$ (two case studies and two studies without data on $Vo_{2peak}$[44,54] were excluded) reported a significant increase after training, with Hjeltnes and Wallberg-Henriksson[51] showing improvements only in the subjects with paraplegia. Three studies reported no increase in $Vo_{2peak}$.[42,47,49] For the 13 of 21 studies with an acceptable quality (studies in bold in Table 2), a change in $Vo_{2peak}$ between pre-test and post-test ranged from 5.1% to 33.5% with a mean (SD) of 17.6 (11.2)%. Sixteen of 20 studies with data on $PO_{peak}$ (two case studies and three studies without data on $PO_{peak}$[31,32,41] were excluded) reported a significant increase after training. Four studies reported no increase in $PO_{peak}$.[36,42,43,49] For the 12 of 20 studies with an acceptable quality, the change in $PO_{peak}$ between pre- and post-test ranged from 10.1% to 57.2% with a mean (SD) of 26.1 (15.6)%.

### *Paraplegia and tetraplegia*

Only two of nine studies with data on subjects with both paraplegia and tetraplegia differentiated between these lesion levels.[50,51] As can be seen in Table 2 (studies in bold) and Figure 2a, nine studies of an

**Table 2** Mean (SD) change in $Vo_{2peak}$ and $PO_{peak}$ between pre- and post-test

| Paraplegia | | | | | | | | Tetraplegia | | | | | | | | Paraplegia and tetraplegia | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Study | *n* | Peak PO | | % change | Peak $Vo_2$ | | % change | Study | *n* | Peak PO | | % change | Peak $Vo_2$ | | % change | Study | *n* | Peak PO | | % change | Peak $Vo_2$ | | % change |
| | | Pre-test (W) | Post-test (W) | | Pre-test (L/min) | Post-test (L/min) | | | | Pre-test (W) | Post-test (W) | | Pre-test (L/min) | Post-test (L/min) | | | | Pre-test (W) | Post-test (W) | | Pre-test (L/min) | Post-test (L/min) | |
| **ACE** | | | | | | | | **ACE** | | | | | | | | **ACE** | | | | | | | |
| **El Sayed 2005**[30] | 5 | 168<br>(38) | 185<br>(24) | 10.1* | 1.80<br>(0.1) | 1.94<br>(0.05) | 7.2* | DiCarlo 1982 [33] | 1 | | | N/a | | | 45 | DiCarlo 1983[36] | 4 | 68.6<br>(22.9) | 106.7<br>(52.8) | 64.3$^{ns}$ | 0.89<br>(0.18) | 1.47<br>(0.48) | 60.5* |
| **Davis 1991**[31] | 18 | | | n/a | 1.46 | 1.69 | 15.9* | DiCarlo 1988 [34] | 8 | 34<br>(1.1) | 42<br>(1.6) | 23.8* | 0.90 | 1.79 | 99* | | | | | | | | |
| *Control* | *6* | | | *n/a* | *1.66*<br>*(0.15)* | *1.71*<br>*(0.12)* | *3* | **McLean 1995** [35] | 14 | 29 | 33 | 13.7** | 0.72 | 0.78 | 8.3** | | | | | | | | |
| **Taylor 1986**[32] | 5 | | | n/a | 1.90 | 2.10 | 10.5* | | | | | | | | | | | | | | | | |
| *Control* | *5c* | | | *n/a* | *1.33* | *1.38* | *4* | | | | | | | | | | | | | | | | |
| **WCE** | | | | | | | | **WCE** | | | | | | | | **WCE** | | | | | | | |
| **Bougenot 2003**[37] | 7 | 74 | 88 | 19.6** | 2.19 | 2.55 | 16* | Whiting 1983[40] | 2 | 37 | 49 | 33 | 0.87 | 1.02 | 8.6 | Gass 1980[41] | 7 | | | n/a | 0.76<br>(0.34) | 1.03<br>(0.42) | 34.8** |
| **Tordi 2001**[38] | 5 | 45 | 55 | 22.2* | 1.37 | 1.57 | 14.3* | | | | | | | | | **Hooker 1989**[42] | 5MI | 33<br>(33) | 38 | 13.3$^{ns}$<br>(0.67) | 1.31<br>(0.63) | 1.47 | 12$^{ns}$ |
| Foll de Moro 2005[39]# | 6 | 49 | 65 | 34.4* | 1.21 | 1.64 | 36* | | | | | | | | | | 6LI | 33<br>(29) | 41<br>(30) | 24 | 1.32<br>(0.56) | 1.47<br>(0.45) | 11$^{ns}$ |
| | | | | | | | | | | | | | | | | Midha 1999[43] | 10 | 73 | 68 | –6.6$^{ns}$ | 1.41<br>(0.44) | 1.82<br>(0.46) | 29* |
| **OTHER** | | | | | | | | **OTHER** | | | | | | | | **OTHER** | | | | | | | |
| **Duran 2000**[44]# | 13 | 90<br>(24) | 110<br>(26.1) | 22.2*** | | | n/a | **Dallmeijer 1997**[49] | 8T<br>5U | 29<br>16 | 28<br>17 | −4.3$^{ns}$<br>11$^{ns}$ | 1.13<br>0.59 | 1.04<br>0.62 | −8.70$^{ns}$<br>5.1$^{ns}$ | **deGroot 2003**[52]# | 3HI<br>3LI | 70<br>53 | 90<br>68 | 59*<br>24 | 1.20<br>0.90 | 1.74<br>1.06 | 50*<br>17 |
| **Jacobs 2001**[45] | 10 | 49<br>(8) | 56<br>(8) | 16.1* | 1.45<br>(0.22) | 1.88<br>(0.31) | 29.7** | *Control* | *7* | *15* | *17* | *14.7$^{ns}$* | *0.70* | *0.66* | *6.1$^{ns}$* | | | | | | | | |
| **Nash 2001** [46] | 5 | 38<br>(7) | 49<br>(8) | 30.4* | 1.32<br>(0.4) | 1.68<br>(0.4) | 30,3** | | | | | | | | | Nilsson 1975[53] | 7 | 45<br>(15) | 60<br>(16) | 31** | 1.88 | 2.07 | 12* |

(*Continued*)

**Table 2** (*Continued*)

| Study | $n$ | Peak PO | | % change | Peak $\dot{V}O_2$ | | % change |
|---|---|---|---|---|---|---|---|
| | | Pre-test (W) | Post-test (W) | | Pre-test (L/min) | Post-test (L/min) | |
| Rodgers 2001[47] | 15 | 46<br>(29) | 53<br>(35) | 14.6* | 1.03<br>(0.36) | 1.10<br>(0.23) | 6.8$^{ns}$ |
| Sutbeyaz 2005[48]# | 20 | 31<br>(13) | 52<br>(17) | 65*** | 9.86<br>(4.21) | 14.6<br>(4.03) | 48*** |
| **Cooney 1986[50]** | 5 | ? | ? | 29.5$^?$ | ? | ? | 27.3$^?$ |
| **Hjeltne 1998[51]#** | 10 | 75<br>(6) | 107<br>(5) | 42.7*** | 1.37<br>(0.08) | 1.75<br>(0.08) | 27.7*** |
| **Cooney 1986[50]** | 5 | ? | ? | 57.2$^?$ | ? | ? | 29.7$^?$ |
| **Hjeltnes 1998[51]#** | 10 | 22<br>(2) | 32<br>(7) | 45.5* | 0.78<br>(0.07) | 0.81<br>(0.06) | 3.8$^{ns}$ |
| Knuttson 1973[54]# | 10 | 40<br>(27) | 57<br>(31) | 40.5* | | | n/a |

Level of significance (between pre- and post-test) $*P < 0.05$, $**P < 0.01$, $***P < 0.001$, ns, not significant.
ACE, arm crank exercise; WCE, wheelchair exercise; OTHER, all other modes of exercise; n/a, not available; T, trained; U, untrained; LI, low intensity; MI, moderate intensity; HI, high intensity.
Papers in **bold** are studies of acceptable quality. Studies with # involve subjects with time since injury less than 1 year.
From Davis *et al.* only results of all subjects after 8 weeks training.
For the sake of comparability, we converted the $\dot{V}O_{2peak}$ values in mL/kg/min into L/min in several studies.[32,34,37,38,43,48,50,52]

acceptable quality examined the effect on $\dot{V}O_{2peak}$ in people with paraplegia,[30–32,37,38,45,46,50,51] including one study examining subjects with a time since injury of less than one year[51] and two studies with a randomized control group.[31,32] Improvements in $\dot{V}O_{2peak}$ for subjects with paraplegia ranged between 7%[30,32] and 30%.[45,46,50,51]

Eight studies of an acceptable quality[30,37,38,44–46,50,51] used $PO_{peak}$ as outcome measures in people with paraplegia (Table 2, Figure 2b). Two studies however, included subjects with a time since injury of less than one year.[44,51] The range of improvements in $PO_{peak}$ was between 10% and 30% in most studies; except for one study (40%).[51] None of these eight studies however used a control group.

Only four studies of acceptable quality are available on the effect on $\dot{V}O_{2peak}$ and $PO_{peak}$ in people with tetraplegia.[35,49–51] Hjeltnes and Wallberg-Henriksson[51] (time since injury of less than one year) and Dallmeijer *et al.*[49] found no effect on $\dot{V}O_{2peak}$. McLean *et al.*[35] found only a small effect of 8.3%, while Cooney and Walker[50] found a considerably higher improvement of 29.7% after a resistance training circuit. Only Dallmeijer *et al.*[49] included a relevant, but not randomized, (sedentary) control group. Except for Dallmeijer *et al.*, all studies[35,50,51] found a significant effect on $PO_{peak}$, ranging from 13 to 57% (Figure 2b).

### *Training mode*

Figure 3a,b shows effects of different training modes on $\dot{V}O_{2peak}$ and $PO_{peak}$. Again the variation among studies is considerable for both outcome measures. Taking into account only the studies with an acceptable quality, and with subjects at least one year post injury (Figure 3a), the gain in physical capacity – especially in $\dot{V}O_{2peak}$ – appears to be higher (30%) in three[45,46,50] out of the four studies using 'other modes of training',[45,46,49,50] when compared with arm crank exercise or wheelchair exercise (10–20%). All three studies performed circuit resistance training and in two studies[45,46] the same training protocol was used. In the fourth study of 'other modes of training',[49] in which data were corrected for change in the control group, no training effect of 'quad rugby' was found, but this study used a low training intensity and frequency.

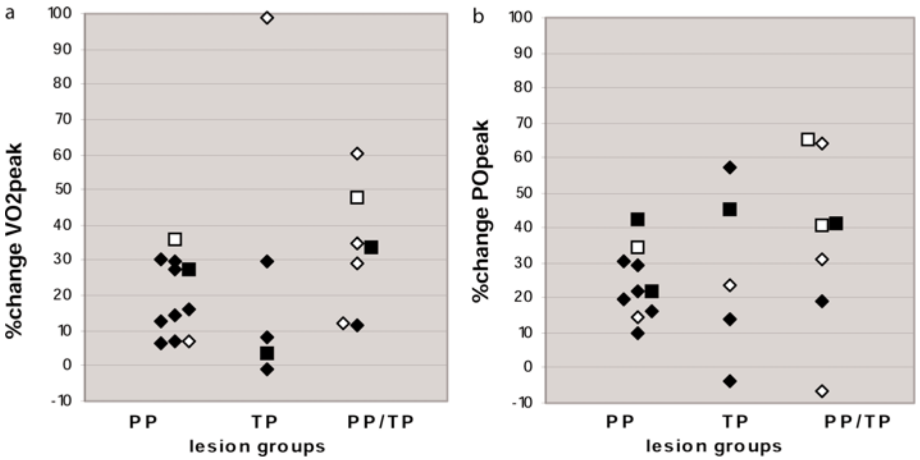

**Figure 2** The effects on $\dot{V}O_{2peak}$ (a) and $PO_{peak}$ (b) between different lesion groups. TP, tetraplegia; PP, paraplegia. Square symbols are studies including subjects with time since injury <1 year and diamond symbols are studies with time since injury >1 year. Filled symbols are studies of an acceptable quality and open symbols are studies of a lower quality. Results from the studies of Taylor *et al.*,[32] Davis *et al.*[31] and Dallmeijer *et al.*[49] are corrected for changes in control group. Results from the studies of Cooney and Walker[50] and Hjeltnes and Wallberg-Henriksson[51] are depicted separately for tetraplegia and paraplegia.

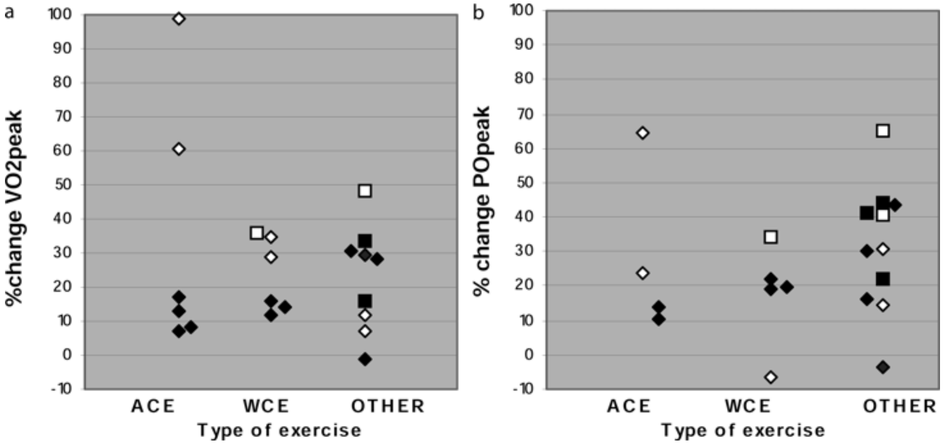

**Figure 3** The effects on $\dot{V}O_{2peak}$ (a) and $PO_{peak}$ (b) between different training methods. ACE, arm crank exercise; WCE, wheelchair exercise; OTHER, other modes of training. Square symbols are studies including subjects with time since injury <1 year and diamond symbols are studies with time since injury >1 year. Filled symbols are studies of an acceptable quality and open symbols are studies of a lower quality. Results from studies of Taylor *et al.*,[32] Davis *et al.*[31] and Dallmeijer *et al.*[49] are corrected for changes in a control group. The results from the studies of Cooney and Walker[50] and Hjeltnes and Wallberg-Henriksson[51] are combined for tetraplegia and paraplegia.

## Discussion

The literature on the effects of upper body training in people with spinal cord injury appears to be limited in quantity and quality. One of the problems in research concerning persons with spinal cord injury is the fact that the intervention groups (and control groups if present) are almost always rather small and heterogeneous, and the statistical power of the studies is thus limited. The heterogeneity is caused by variation in lesion level, completeness of lesion, gender and age. Time since injury (TSI) and training status are also factors that are expected to affect the training effects.

Besides the heterogeneous population, different training protocols and modes account for the variation in outcome of the different studies. Moreover, the different maximal exercise test designs to measure physical capacity (i.e. interval or continuous, the initial power, power increments at each step and the duration of the exercise bouts) might influence the test results. For these reasons the different studies cannot be easily compared and interpreted.

## Methodological quality

According to Martin Ginis and Hicks,[56] the value of an RCT is indisputable, but in people with spinal cord injury it appears to be a very difficult design because of the heterogeneity of the group and due to the more practical problems of vulnerability for diseases and transportation to the training facility. As a consequence the risk of drop-out or poor compliance is high, especially in people with higher lesion levels. Randomization is the most important tool to deal with heterogeneity, however, the problem remains that large subject numbers are needed to secure statistical power in heterogeneous groups. Therefore the value of studies with a quasi-experimental design should certainly – but carefully – be taken into account, because otherwise important and scarce information will be lost. Only two out of 25 studies appeared to be relevant RCTs, but both were of a relatively low methodological quality. Therefore, we decided to include and assess the quality of non-randomized controlled clinical trials as well, using the quality list by van Tulder *et al.*[14] Items common to RCTs are scored, but also other relevant items such as compliance, drop-out and adverse effects. Studies without an RCT design still could achieve a low but acceptable score by scoring points on the other items. The overall mean score for all studies was just below the cut-off point of 50%. Due to the overall low methodological quality (absence of control groups) and the heterogeneity of the studies, statistically pooling of the results could not be performed in the current study.

## Training effects

### *Overall*

Almost all studies concluded that a training intervention has a positive effect on the physical capacity as reflected by improvements in $\dot{V}O_{2peak}$ and $PO_{peak}$. One must be aware, however, that studies that did not find any significant changes may have remained unpublished. Above that, the overall quality of the presented studies is limited. The magnitude of the training effect appears to differ considerably between studies. From our review it appears that studies of a lower methodological quality generally tended to find larger training effects, especially in $\dot{V}O_{2peak}$ as is shown in Figures 2a and 3a.

Only the studies of Taylor *et al.*[32] and Davis *et al.*[31] were executed with small but relevant randomized control groups, and both show modest improvements in $\dot{V}O_{2peak}$ of 10.5% (exp.) versus 4% (control) and 15.9% (exp.) versus 3% (control), respectively (Table 2). The post-test of the experimental group in the study by Taylor *et al.*[32] showed a significant improvement in $\dot{V}O_{2peak}$ compared to the pre-test, and a trend but not significant improvement in comparison to the control group. In this instance the small subject sampling probably compromised the statistical power. In the study of Davis *et al.*,[31] a significant difference between the control and experimental groups was only attained when the subjects continued training for a longer period than eight weeks (i.e. after 16 and 24 weeks of training). In Table 2 we only reported the results after eight weeks of training because the reported drop-out rate was regarded to be unacceptable after continuation of the training period.

Most studies of acceptable quality were executed without a control group and found gains in both $PO_{peak}$ and $\dot{V}O_{2peak}$ within a range of 10–30%. The effect of training in the studies without a control group may be overestimated, as is shown from the studies with a control group.[31,32,49] The influence of a learning effect (on the test) or normal daily fluctuations in health and fitness (not uncommon in people with a high spinal cord injury) may appear as confounding factors. In most studies in the current review it is unclear to what extent possible methodological confounds might have influenced the training effects.

We decided to highlight training studies in subjects injured within the last year (time since injury less than one year)[39,44,48,51,52,54] (Table 2 and Figures 2 and 3) because the effects on the outcome measures may possibly be (also) attributed to neurological recovery, especially in people with tetraplegia. Higher gains in physical capacity are therefore expected in this group. Higher gains, however, can also be explained by an extremely inactive (often bed-bound) period in the first period after injury, which seems to be confirmed by the data on change in $PO_{peak}$. Studies with a time since injury of less than one year show higher $PO_{peak}$ increases compared with studies with a time since injury of more than one year (Figures 2b and 3b). However, there is no clear evidence to assume higher gains in $\dot{V}O_{2peak}$. For example, Hjeltnes and Wallberg-Henriksson[51] found no improvement in $\dot{V}O_{2peak}$ when training people with tetraplegia shortly after injury, whereas a large improvement was seen in people with paraplegia. Also, De Groot *et al.*[52] found an improvement in $\dot{V}O_{2peak}$ of 33.5% in a mixed group of people with paraplegia and tetraplegia during rehabilitation. Unfortunately no control groups were present in these studies to control for the possible influence of neurological recovery.

### *Paraplegia and tetraplegia*

Due to the low number of studies of acceptable quality (especially in people with tetraplegia) it is difficult to draw conclusions on training effects in relation to lesion level. The few available studies on people with tetraplegia vary considerably in training effect on both $PO_{peak}$ and $\dot{V}O_{2peak}$. From our review it seems, however, that both paraplegia and tetraplegia may benefit from training and no relative differences in training effect seem to be present. Jacobs and Nash[12] stated that the magnitude of improvement in $\dot{V}O_{2peak}$ is inversely proportional to the level of spinal lesion. However, they referred to absolute values of $\dot{V}O_{2peak}$, whereas in this review we investigated the relative gain (percentage change) in training effect, which is not the same. Moreover it has to be remarked that the training studies on subjects with paraplegia most often examined subjects with lesion level Th6 or below, which may be explained by the fact that lesion levels above Th6 are relatively scarce due to the protection of the thorax. The results on gain in physical capacity may not reflect those with high lesion paraplegia. People with lesion of Th6 or higher may experience autonomic dysfunction that alters cardiac functions during acute exercise. As such, people with injuries above Th4 may react differently to training than subjects with lesions below T6[13] as well as those with injuries above T1. However, from the current results on the people with paraplegia and tetraplegia, the relative gain in physical capacity due to upper body training does not necessarily seem to be related to level of lesion.

### *Training mode*

From the limited studies of acceptable quality it is difficult to say whether a training effect is more prominent in arm crank exercise, wheelchair exercise or other training methods. On the other hand the training effect in the three studies on circuit resistance training[45,46,50] seems to be relatively high compared to the studies with arm crank exercise and wheelchair exercise. Unfortunately, no control group was present in these three studies and the training status of the subjects was not described. Moreover, the relatively long training duration (45 min) and long training period (12 weeks) may also have contributed to the larger training effect. However, the relatively long and variable training sessions appeared to be well sustainable and tolerated, as 'no adverse effects' were reported. Circuit resistance training (including short bouts of arm crank exercise) may therefore be a more effective method of training compared with isolated wheelchair exercise and arm crank exercise, because of the variety in training stimulus. Last but not least, more variety in training may be more attractive to perform and is likely to increase motivation and adherence of the subjects.

### *Other outcome measures*

Muscle strength and pulmonary function are other outcome measures that contribute to the level of physical capacity.[9] It appeared to be impossible to compare the effects on muscle strength between the few studies with available data,[44,45,47,49,51,53] because of large differences in tested muscle groups and test methods (dynamic, isometric, manual, etc.). All studies claim significant improvements in muscle strength, but again, no control groups were present in any of the studies involved. Other upper body training studies in spinal cord injury,[16,18,19] all excluded from this review because they lacked data on $\dot{V}O_{2peak}$ and $PO_{peak}$, also reported improvement in muscle strength. In the high quality RCT of Hicks *et al.*[19] improvements in different muscle groups were reported between 19 and 34%.

From the few studies on pulmonary function[32,39,41,48] only one study was of an acceptable quality and no gain was found.[32] Only Sutbeyaz *et al.*,[48] who incorporated respiratory exercises in the training sessions, found a (low) improvement of 1.1% in forced vital capacity (FVC). Other upper body training studies in spinal cord injury, again excluded from this review because they lacked data on $V\text{O}_{2\text{peak}}$ or $\text{PO}_{\text{peak}}$, found an improvement of 9%[18] in FVC or no improvement at all,[20] although both studies lacked a control group.

## Conclusion

In general, the methodological quality of the studies on the effects of upper body training in people with a spinal cord injury is low (e.g. RCTs are scarce) and acceptable in just over 50% of the studies. The results of this review suggest that evidence is weak to support the view that controlled upper body exercise increases the physical capacity of people with spinal cord injury. The magnitude in improvement in $\text{PO}_{\text{peak}}$ and $V\text{O}_{2\text{peak}}$ varies considerably among studies. For the studies of an acceptable (but still rather low) quality a range in increase of 10–30% is common. Relatively few studies have been executed in people with a tetraplegia or high paraplegia (>Th6). Nevertheless, the relative gain in $\text{PO}_{\text{peak}}$ and $V\text{O}_{2\text{peak}}$ after training seems to be comparable between both lesion groups. When looking at differences between training modes, circuit resistance training, including a programme of weight lifting and arm cranking or other aerobic exercises, may appear to be more effective in increasing physical capacity than wheelchair exercise or arm crank exercise only. This statement, however, is based on a trend in the data rather than empirical testing and further study is required to confirm these findings. Due to the low number of studies and the overall low quality it is not possible, however, to derive definitive – evidence-based – conclusions and guidelines when comparing training effects between lesion groups or different training modes.

### Recommendations

Regular exercise in people with spinal cord injury seems beneficial for overall fitness, even when instituted early after injury and for those with high spinal cord lesions. Continued and extended research is clearly needed to find stronger evidence to support this view. It is very important for future research to perform training studies with a high methodological quality in the field of upper body training in people with spinal cord injury. An urgent need for RCTs exists, especially in people with tetraplegia. The RCT design is more complicated in people with spinal cord injury and may require multicentre collaboration to limit effects of heterogeneity, and to solve more practical problems such as transportation to the training facility in order to secure sufficiently large subject numbers and thus statistical power. Furthermore, a more detailed study description of the subject selection and population, training and test protocol, drop-out rate, compliance and adverse effects are necessary to improve the methodological quality and comparability of future studies. Additional research should focus on effects of different training protocols and modes, eventually resulting in training guidelines for (un-)trained people with different levels of spinal cord injury.

### Clinical messages

- There is weak evidence to support the importance and use of upper body exercise to improve physical capacity in people with a spinal cord injury.
- Based on the limited data, no definite recommendation can be given regarding the most adequate mode of exercise, training intensity, frequency or duration.

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### Contributors

LVDW monitored progress, designed the methodology and revised the paper. AJD initiated the study, designed the methodology and revised the paper. HH revised the paper. ET carried out data collection and methodological quality assessment. LV designed the methodology, carried out data collection and methodological quality assessment and wrote the paper.

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