SDC 2: Effect of exercise training on cardiac, autonomic and cardiometabolic outcomes in SCI with high-CVRF

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| **Authors, date** | **Training** | | **n** | **Age (yr)** | **TSI (yr)** | **Level of injury** | **Methods / VO2 test** | **Main outcomes** | **Baseline value** | **Changes after training** |
| ***VO2peak and Fitness*** | |  |  |  |  |  |  |  |  |  |
| ***Cervical injuries*** |  | |  |  |  |  |  |  |  |  |
| **Wheeler, 2002**[**59**](#_ENREF_59) | FES rowing | | 6 | 42 ± 18 | 14 ± 12 | C7–T12 | Uncontrolled study | Peak VO2, L/min | 1.81 ± 0.41 | ↑ 11.2%, *P* < .001 |
|  |  | |  |  |  |  | 12 wk 3x/wk., 75%, 30' | Peak HR, bpm | 167.5 ± 20.9 | No changes |
|  |  | |  |  |  |  | Test: FES-rowing | Peak VE, L/min | 84 ± 27.2 | No changes |
|  |  | |  |  |  |  |  | Peak RER | 0.98 ± 0.12 | NS ↑ upto 1.07 |
| **Valent, 2009**[**51**](#_ENREF_51) | Hand cycling | | 22 | 39 ± 12 | 10 ± 7 | C5-T1 | Uncontrolled study | Peak VO2, L/min | 1.32 ± 0.40 | ↑~10% *P* < .05 |
|  |  | |  |  |  | ASIA A-D | 12 wk 2x/wk., 35-45' | Peak PO, W | 42.5 ± 21.9 | ↑~20% *P* < .05 |
|  |  | |  |  |  |  | Test: Hand-cycling treadmill |  |  |  |
| **Hoekstra, 2013**[**50**](#_ENREF_50) | Robotic gait | | 10 | 49 ± 14 | >1 - 35 | C3-T10 | Uncontrolled study | Peak VO2, L/min | 1.16 ± 0.40 | No changes |
|  |  | |  |  |  | ASIA C-D | 10-16 wk, 2-3/wk., 20-40' | Submax VO2, L/min | 0.75 ± 0.18 | No changes |
|  |  | |  |  |  |  | Test: Armcrank ergometer | submax HR, bpm | 116 ± 14 | ↓ 6%, *P* = .02 |
|  |  | |  |  |  |  |  | Exercise Intensity - METs | 2.1 ± 0.9 | No changes |
| **Bakkum, 2015**[**60**](#_ENREF_60) | FES cycle + arms | | 10 | 48 ± 10 | 20 ± 8 | C3-T10 | Randomized controlled trial | Peak VO2, L/min | 1.19 ± 0.20 | ↑12% vs. +3%, (NS ≠ gps) |
|  | Hand cycle | | 10 | 47 ± 9 | 16 ± 6 | C2-L2 | 16-wk, x/wk., 30' | Peak PO, W | 35.9 ± 9.5 | ↑15% vs. +4%, (NS ≠ gps) |
|  |  | |  |  |  | ASIA A-D | Test in respective mode | Resting HR, bpm | 73 ± 2 | ↓ 8% overall (NS ≠ gps) |
|  |  | |  |  |  |  |  | PA score, (PASIPD) h/wk | 6.3 ± 1.9 | ↑ 224 % vs. 150%, *P* = .10 |
| **Van des Scheer, 2016**[**52**](#_ENREF_52) | Wheelchair treadmill | | 14 | 42–64 | 13–29 | C4-L5 | Randomized controlled trial | Peak VO2, L/min | 1.02 | No changes and no ≠ |
|  | Control | | 15 | 46–62 | 14–31 | C4-L5 | 16 wk 2x/wk., 30' | Peak PO, W | 43.6 | No changes and no ≠ |
|  |  | |  |  |  | Asia A-D | Test: Wheelchair treadmill | PA score, h/wk | 5.3 | No changes and no ≠ |
|  |  | |  |  |  |  |  | Distance km/wk | 7.4 | No changes and no ≠ |
| **Gorman, 2019**[**53**](#_ENREF_53) | Aquatic | | 15 | 47 ± 10 | 12 ± 12 | C2-T12 | Randomized controlled trial | Peak VO2, Aqua, ml/kg/min | 13.3 ± 3.1 | ↑8% vs. Robotic |
|  | Robotic gait | | 18 | 45 ± 13 | 6 ± 4 | C2-T12 | 12 wk, 3x/wk., 40-45' | Peak VO2  Robo, ml/kg/min | 16.5 ± 5.4 | No change |
|  |  | |  |  |  | ASIA C-D | Test: Armcrank ergometer | Peak VO2 robotic treadmill | 14.9 ± 4.3 | ↑ 15% vs. baseline |
|  |  | |  |  |  |  |  | CO 80% of peak, L/min |  |  |
| ***Thoracic injuries*** | |  |  |  |  |  |  |  |  |  |
| **Berry, 2008**[**48**](#_ENREF_48) | FES-cycling | | 11 | 42 ± 8 | 10 ± 7 | T3-T9 | Uncontrolled study | Peak VO2, L/min | 0.54 ± 0.14 | ↑ 56% |
|  |  | |  |  |  | ASIA A | 52 wk 5x/wk., 60' | Peak PO, W | 8.4 ± 3.2 | ↑ 132%, *P* = .001 |
|  |  | |  |  |  |  | Test: FES-cycling ergometer | Peak HR, pbm | 82 ± 8 | ↑ 14%, *P* < .05 (9 mth) |
|  |  | |  |  |  |  |  | Training duration vs. VO2Peak |  | r2 = 0.52, *P* = .012 |
| **Carty, 2012**[**49**](#_ENREF_49) | NMES (2–8Hz) | | 14 | 45 ± 8 | 11 ± 11 | T4-T11 | Prospective cohort study | Peak VO2, L/min | 1.09 ± 0.20 | ↑ 21%, *P* = .001 |
|  | Quad + Hamstring | |  |  |  | ASIA A-B | 8 wk, 5/wk., 60' | Peak HR, pbm | 159 ± 17 | ↑ 3%, *P* = .03 |
|  |  | |  |  |  |  | Test: Wheelchair treadmill |  |  |  |
| ***Cardiac structure and function*** | |  |  |  |  |  |  |  |  |  |
| **Schumacher, 2009**[**66**](#_ENREF_66) | Elite athletes | | 25 | 36 ± 11 | > 3 | C6-S5 | Cross-sectional analysis | VO2peak, L/min | 1.4 ± 0.3 | > 85% in athletes, *P* < .05 |
|  | Untrained | | 10 | 45 ± 18 | > 3 | C6-S5 | > 3 yr 15h/wk endurance | HRmax, bpm | 153 ± 42 | > 13% in athletes, *P* < .05 |
|  |  | |  |  |  |  | CO2 rebreathing method | Cardiac volume | 793 ± 164 | < 4% in athletes, *P* < .05 |
|  |  | |  |  |  |  | Echocardiography | Hb concentration, mmol/l | 8.8 ± 1.4 | > 8% in athletes, *P* < .05 |
|  |  | |  |  |  |  |  | Total Hb mass, mmol | 390 ± 130 | > 19% in athletes, *P* < .05 |
| **Brurok, 2011**[**61**](#_ENREF_61) | FES cycling + arm | | 6 | 40 ± 11 | 17 ± 8 | C7, T1-T9 | Uncontrolled study | VO2peak, ml/min/kg | 24.6 ± 3.9 | ↑ 24%, *P* < 0.05 |
|  |  | |  |  |  | ASIA A | 8 wk, 3/wk., intervals | CO 80% of peak, L/min | 12.4 ± 1.9 | ↑ 27%, *P* < 0.05 |
|  |  | |  |  |  |  | Single breath acetylene | SV 80% of peak, ml/beat | 77.7 ± 9.9 | ↑ 33%, *P* < 0.05 |
| **Milia, 2014**[**54**](#_ENREF_54) | Arm crank | | 9 | 41 ± 11 | 5-15 | T4–L1 | Uncontrolled study | VO2peak, L/min | 1.4 ± 0.2 | ↑ 11%, *P* < 0.05 |
|  |  | |  |  |  | ASIA A | 1 yr / 3-5h /wk, 60%Wmax | ∆CO post Ischemia, mL/min | 220 ± 745 | ↑ 247%, *P* < 0.05 |
|  |  | |  |  |  |  | Impedance cardiography | ∆VFR post Ischemia, mL/sec | −15 ± 35 | ↑ to +51 ± 50 |
|  |  | |  |  |  |  | Resting post-ischemia |  |  |  |
| ***Autonomic function*** | |  |  |  |  |  |  |  |  |  |
| **Stevens, 2015**[**55**](#_ENREF_55) | Submerged | | 11 | 48 ± 13 | 5 ± 8 | C4-L2 | Uncontrolled study | HR wk 2/3, bpm | 102 (93-115) | ↓7% d6 vs. d1, *P* < .001 |
|  | treadmill | |  |  |  | ASIA C-D | 8 wk, 3x/wk., 15-24' | HR wk 4/5, bpm (> speed) | 118 (108-126) | ↓14% d6 vs. d1, *P* < .001 |
|  |  | |  |  |  |  | Chest monitor last 15" | HR wk 6/7, bpm (>> speed) | 126 (121-138) | ↓ 17% d6 vs. d1, *P* < .001 |
| ***Cardiovascular function and blood markers of cardiovascular risk*** | | | | | |  |  |  |  |  |
| **Griffin, 2009**[**56**](#_ENREF_56) | FES cycling | | 18 | 40 ± 2 | 11 ± 3 | C4-T7 | Uncontrolled study | Total Chol, mg/dl | 157.9 ± 6.3 | No change |
|  |  | |  |  |  |  | 10 wk, 2-3/wk., 30' | HDL-C, mg/dl | 34.2 ± 2.0 | ↓11% *P* < .05 |
|  |  | |  |  |  |  | Blood samples | IL-6, pg/ml | 4.91 ± 1.10 | ↓22% *P* < .05 |
|  |  | |  |  |  |  |  | TNF-α, pg/ml | 11.8 ± 0.6 | ↓4% *P* < .05 |
|  |  | |  |  |  |  |  | CRP, mg/L | 15.9 ± 1.5 | ↓19% *P* < .05 |
| **Hubli, 2014**[**73**](#_ENREF_73) | Elite hand-cycle | | 10 | 41 ± 6 | 19 ± 6 | C2–T5 | Cross-sectional comparison | Aortic PWV, m/sec | 8.7 ± 2.5 | < 21% in athletes, *P* =.04 |
|  | Non-elite | | 10 | 42 ± 11 | 17 ± 11 | C4-T3 | 17 ± 4 vs. 1 ± 2 h/wk. | Resting supine MAP, mmHg | 91 ± 19 | NS ≠ in trained (81 ± 10) |
|  |  | |  |  |  |  | Applanation tonometry | EDV 3’ post Ischemia, mL | 7.2 ± 22.2 | ↑ 370% |
| **Jeon, 2010**[**62**](#_ENREF_62) | FES-rowing | | 6 | 48.6 ±6 | NA | T4-T10 | Uncontrolled study | VO2peak, ml/min/kg | 21.4 ± 1.23 | ↑ 8%, *P* < .05 |
|  |  | |  |  |  |  | 12 wk, 3-4/wk., 30' | plasma glucose, mg/dL | 103.2 ± 6.8 | ↓ 10%, *P* .28 |
|  |  | |  |  |  |  | Fasting blood samples | plasma leptin, ng/dL | 6.9 ± 1.7 | ↓ 28%, *P* .28 |
|  |  | |  |  |  |  |  | Fat mass, % | 25.5 ± 1.8 | ↓ 5%, *P* = .07 |
|  |  | |  |  |  |  |  | insulin sensitivity | 3.6 0.8 | No change |

**Definition of abbreviation**: ASIA, American Spinal Injury Association impairment scale; Bsl, baseline; CO, cardiac output; CRP, C reactive protein; EDV, end diastolic volume; Gp, group; Hb, hemoglobin; HDL, high density lipoprotein, HR, heart rate; IL-6, interleukin 6; PA, physical activity; PO, power output; PWV, pulse wave velocity; RER, respiratory exchange ratio; SV, stroke volume; TNF-α, tumor necrosis factor alpha; VE, minute ventilation; VFR, ventricular filling rate; VO2peak, peak O2 uptake.