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ORIGINAL ARTICLE

# A pilot randomized controlled trial of 6-week combined exercise program on fasting insulin and fitness levels in individuals with spinal cord injury

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## Abstract

**Purpose** The aim of this randomized controlled trial study was to investigate the effect of combined exercise program on the fasting insulin and fitness levels of people with spinal cord injury (SCI).

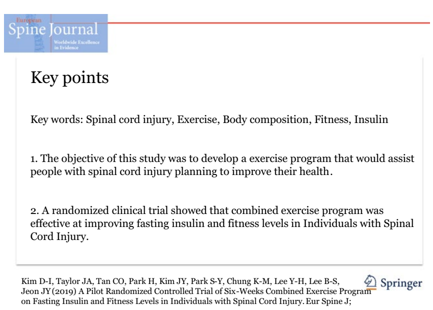
**Methods** A total of 19 individuals with SCI participated in a combined exercise program consisting of aerobic and resistance exercises for 60 min per day, 3 days per week for 6 weeks. Peak oxygen consumption, body mass index, percent body fat, waist circumference, shoulder abduction and adduction, shoulder flexion and extension, elbow flexion and extension, fasting insulin levels, and homeostasis model assessment of insulin resistance (HOMA-IR) levels were measured at baseline and after the intervention.

**Results** The 6-week exercise program significantly decreased the average fasting insulin (baseline: 7.5 ± 4.7 μU/ml vs. post-intervention: 4.5 ± 2.2 μU/ml, $p < 0.05$) and HOMA-IR (baseline: 1.5 ± 1.0 vs. post-intervention: 0.9 ± 0.4, $p < 0.05$) in the exercise group, whereas there was no change in control group (between group difference, mean fasting insulin: −3.2 μU/ml, $p = 0.003$; mean HOMA-IR: −0.66, $p = 0.001$). In addition, muscle strength of the shoulder flexors, extensors, abductors, adductors, and elbow flexors was significantly improved in the exercise group compared to the controls.

**Conclusion** A combined exercise program is effective in decreasing fasting insulin and HOMA-IR levels while improving fitness in those with SCI.

### Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.



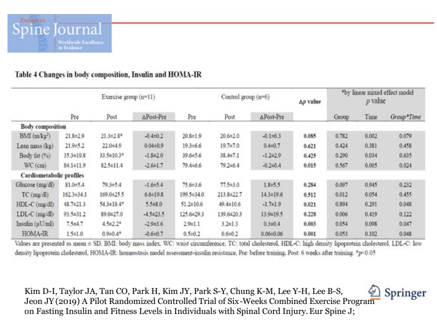



Table 4 Changes in body composition, Insulin and HOMA-IR

| | Exercise group (n=11) | | | Control group (n=6) | | | Δp value | *by linear mixed effect model p value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | ΔPost-Pre | Pre | Post | ΔPost-Pre | | Group | Time | Group*Time |
| **Body composition** | | | | | | | | | | |
| BMI (m/kg²) | 21.8±2.9 | 21.3±2.8* | -0.4±0.2 | 20.8±1.9 | 20.6±2.0 | -0.1±0.3 | 0.085 | 0.782 | 0.002 | 0.079 |
| Lean mass (kg) | 21.9±5.2 | 22.0±4.9 | 0.04±0.9 | 19.3±6.6 | 19.7±7.0 | 0.4±0.7 | 0.621 | 0.424 | 0.381 | 0.458 |
| Body fat (%) | 35.3±10.8 | 33.5±10.3* | -1.8±2.0 | 39.6±5.6 | 38.4±7.1 | -1.2±2.9 | 0.425 | 0.290 | 0.034 | 0.635 |
| WC (cm) | 84.1±11.9 | 82.5±11.4 | -2.6±1.7 | 79.4±6.6 | 79.2±6.4 | -0.2±0.4 | 0.015 | 0.567 | 0.005 | 0.024 |
| **Cardiometabolic profiles** | | | | | | | | | | |
| Glucose (mg/dl) | 81.0±5.4 | 79.3±5.4 | -1.6±5.4 | 75.6±3.6 | 77.5±3.0 | 1.8±5.5 | 0.284 | 0.097 | 0.945 | 0.232 |
| TC (mg/dl) | 162.3±34.1 | 169.0±25.5 | 6.6±19.8 | 199.5±34.0 | 213.8±22.7 | 14.3±19.6 | 0.512 | 0.012 | 0.054 | 0.455 |
| HDL-C (mg/dl) | 48.7±21.3 | 54.3±18.4* | 5.5±8.0 | 51.2±10.6 | 49.4±10.6 | -1.7±1.9 | 0.021 | 0.894 | 0.291 | 0.048 |
| LDL-C (mg/dl) | 93.5±31.2 | 89.0±27.0 | -4.5±23.5 | 125.6±29.3 | 139.6±20.3 | 13.9±19.5 | 0.228 | 0.006 | 0.419 | 0.122 |
| Insulin (μU/ml) | 7.5±4.7 | 4.5±2.2* | -2.9±3.6 | 2.9±1.1 | 3.2±1.3 | 0.3±0.4 | 0.003 | 0.054 | 0.098 | 0.047 |
| HOMA-IR | 1.5±1.0 | 0.9±0.4* | -0.6±0.7 | 0.5±0.2 | 0.6±0.2 | 0.06±0.06 | 0.001 | 0.053 | 0.102 | 0.048 |

Values are presented as mean ± SD. BMI: body mass index, WC: waist circumference, TC: total cholesterol, HDL-C: high density lipoprotein cholesterol, LDL-C: low density lipoprotein cholesterol, HOMA-IR: homeostasis model assessment-insulin resistance, Pre: before training, Post: 6 weeks after training. *p<0.05

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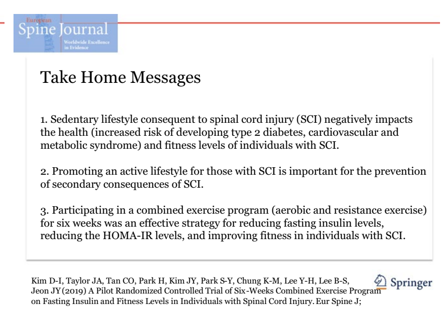


**Keywords** Spinal cord injury · Exercise · Body composition · Fitness · Insulin

### List of Abbreviations

| | |
|---|---|
| SCI | Spinal cord injury |
| HOMA-IR | Homeostasis model assessment of insulin resistance |

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s00586-019-05885-7) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

BMI Body mass index
$VO_2$ Peak Peak oxygen consumption

## Introduction

Sedentary lifestyle consequent to spinal cord injury (SCI) negatively impacts the fitness level and quality of life of individuals with SCI [1–3]. As a result, those with SCI are at increased risk of developing type 2 diabetes, cardiovascular disease [4, 5], and metabolic syndrome [6]. Therefore, promoting an active lifestyle for those with SCI is important for the prevention of secondary consequences of SCI.

Aerobic exercise has been shown to improve insulin resistance [7–9], prevent cardiovascular complications [10, 11], and improve cardiovascular function in those with SCI [7, 9]. In addition to aerobic exercise, resistance exercise is recommended to improve glycemic control and insulin sensitivity in general population [12, 13]. However, most previous studies [7, 9] which investigated the effect of exercise on insulin resistance and cardiovascular health only implemented aerobic exercise, but not resistance exercise in individuals with SCI. Since people with SCI extensively use their upper body for transportation purpose, which involves shoulder flexion and elbow extension (pushing motion), large majority of them experience shoulder joint problems such as subacromial impingement syndrome and rotator cuff tears [14, 15]. Therefore, it would be ideal if people with SCI should strengthen their elbow and shoulder joints with shoulder extension and elbow flexion exercise (pulling motion). However, there is lack of studies which investigated the effect of combined aerobic and resistance exercises on metabolic and musculoskeletal health of people with SCI.

Level of SCI can influence the individuals' ability to perform exercise such as type, intensity, and duration of exercise. Furthermore, type, duration, and intensity of exercise should be differently prescribed according to participants' comorbidity (obesity, type 2 diabetes, cardiovascular disease), shoulder and elbow joint conditions. To maximize health benefits of exercise for individuals with SCI, exercise prescription should be tailored according to the presence of comorbidities, such as type 2 diabetes and hypertension, the existence of joint problems, and the level of injury. However, most studies which demonstrated the beneficial effect of exercise either on cardiometabolic profile and joint problems in individuals with SCI applied same exercise protocols regardless of participants' level of injuries, degree of adiposity, and comorbidities.

In this study, we aim to apply tailored exercise program for individuals with SCI according to their level of injury, adiposity, and other health conditions. The purpose of the current study was to examine the effect of this combined exercise program (aerobic and resistance exercises) on fasting insulin, HOMA-IR, cardiometabolic profiles, muscular strength, and cardiopulmonary fitness in those with SCI.

## Method

### Study design and participants

This was a pilot randomized controlled trial with two arms (exercise vs. standard care) that enrolled 19 individuals with SCI (12 males, 7 females). Inclusion criteria were: (1) SCI > 6 months, (2) 18–65 years of age, and (3) no regular exercise over the prior six months. Exclusion criteria were: (1) cardiovascular disease, (2) uncontrolled type 2 diabetes, (3) uncontrolled hypertension, (4) pressure ulcers, and (5) orthopedic problems. This study was approved by the Institutional Review Board of Yonsei University. Participant characteristics and recruitment procedures are shown in Table 1 and Fig. 1.

### Exercise program

Particular type of exercise an individual with SCI can perform is influenced by the level of injury. Furthermore, the level of adiposity, the existence of joint problems, the presence of type 2 diabetes, and the presence of CVD may also influence the type, intensity, duration, and frequency of exercise in which individuals with SCI can participate. Given this, we developed an exercise program individualized for individuals based on their level of injury, comorbidities, joint conditions, and primary reason for exercise. The detailed information on this program is explained in Tables 2 and 3.

All participants exercised for 60 min per session, three sessions per week, for 6 weeks. Daily exercise program consisted of a 25-min warm-up consisting of 5 min of joint exercises, 15 min of exercise on an arm ergometer, and 5 min of stretching, followed by a 30-min exercise program (resistance, circuit, and aerobic training), and a 5 min of cooldown (stretching) (Table 3), but the contents of the 30-min exercise were customized for each individual depending on the comorbidities and other factors (see Tables 2 and 3). During circuit and aerobic exercise, participants maintained a moderate- to vigorous intensity exercise indicated by a Borg score from 4 to 8 on a scale ranging from 0 (nothing at all) to 10 (very, very hard)] [16]. Exercise intensity was revised weekly based on the intensity achieved in the previous week, and the Borg rating of perceived exertion (RPE) to ensure the safety of the participants [16].

**Table 1** Participant characteristics

| | Sex | Age (years) | Height (cm) | Weight (kg) | BMI (kg/m$^2$) | Waist (cm) | Duration (years) | Level of injury | ASIA* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Male | 23 | 178 | 69.2 | 21.8 | 79 | 2 | C7 | A |
| 2 | Male | 34 | 175 | 56.3 | 18.4 | 69 | 17 | L1 | B |
| 3 | Male | 53 | 182 | 69.8 | 21.1 | 87 | 27 | T10 | A |
| 4 | Male | 32 | 184.5 | 69.9 | 20.5 | 83 | 14 | C6 | A |
| 5 | Female | 38 | 160 | 71 | 27.7 | 113 | 10 | C7 | A |
| 6 | Male | 32 | 175 | 72.3 | 23.6 | 89 | 2 | C4 | A |
| 7 | Female | 41 | 168 | 50.8 | 18 | 79 | 8 | T6 | B |
| 8 | Male | 38 | 176 | 61.8 | 20 | 83 | 12 | T5 | A |
| 9 | Female | 36 | 160 | 51.2 | 20 | 76 | 11 | C6 | B |
| 10 | Female | 35 | 166 | 50.1 | 18.2 | 70 | 8 | C6 | B |
| 11 | Female | 32 | 165 | 57.1 | 21 | 80 | 5 | C7 | B |
| 12 | Male | 43 | 173 | 73.8 | 24.7 | 86 | 11 | T8 | C |
| 13 | Female | 38 | 158 | 52.1 | 20.9 | 73 | 7 | C7 | A |
| 14 | Male | 34 | 179 | 82 | 25.6 | 95 | 4 | C5 | B |
| 15 | Male | 33 | 174 | 68.3 | 22.6 | 87 | 9 | C6 | A |
| 16 | Male | 49 | 171 | 74.6 | 25.5 | 91 | 24 | T10 | A |
| 17 | Male | 35 | 180.8 | 77.6 | 23.7 | 84 | 8 | C5 | B |

Values are presented as mean ± SD. BMI: body mass index, duration: time interval between the onset of injury and exercise training, T: thorax, L: lumbar, C: cervical

*ASIA impairment scale: American spinal cord injury association impairment scale (A, complete injury—no motor or sensory function is preserved in sacral segments S4–S5; B, incomplete injury—sensory function but no motor function is preserved below the neurological level and extends through sacral segments S4–S5; C, incomplete injury—motor function is preserved below the neurological level and more than half of the key muscles below the neurological level have a muscle grade of less than 3)

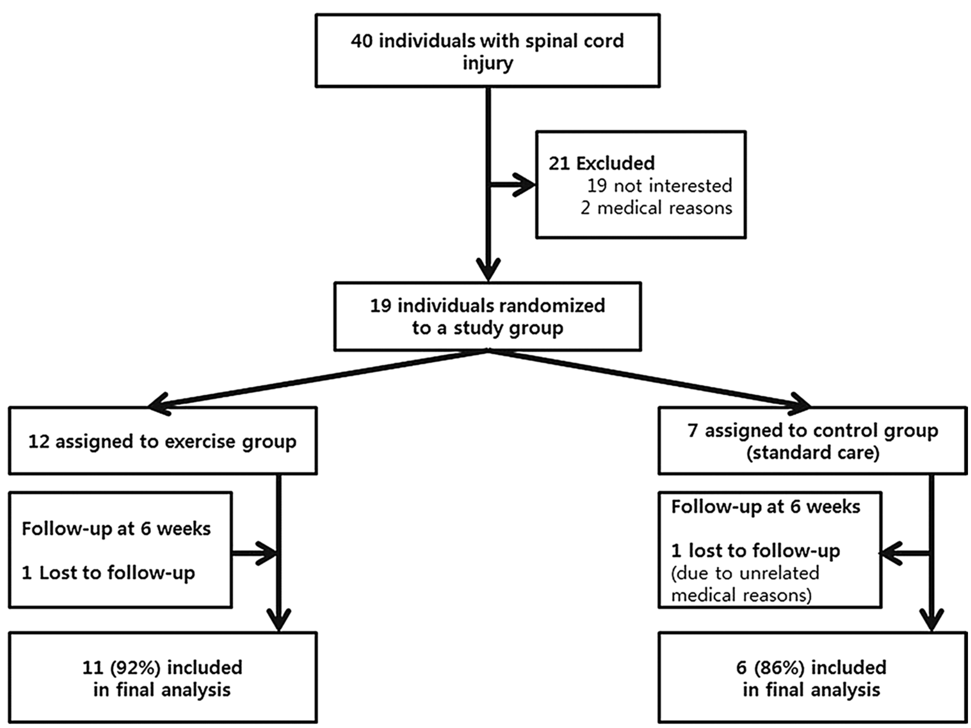


**Fig. 1** CONSORT diagram showing participant flow through the different stages of the study

**Table 2** Factors guiding the development of the tailored combined exercise program for different injury levels

| | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| Screening | Level of injury | Comorbidity | Purpose of exercise | Joint stability |
| Contents | Component of resistance exercise | Exercise frequency and intensity level | Ratio of aerobic, resistance, and circuit training | Rehabilitation exercise |
| Category | A type<br>A1: C4–C6<br>A2: C7–C8<br>A3: T1–T6<br>A4: T7–L2<br>A5: L3<br>A6: L4–l5<br>A7: S1–S2 | B type<br>B1: Metabolic syndrome<br>B2: Hypertension<br>B3: Diabetes<br>B4: Osteoporosis<br>B5: Obesity<br>B6: None | C type<br>C1: Functional fitness<br>C2: Weight loss<br>C3: Muscle strength<br>C4: Cardiovascular fitness | D type<br>D1: Shoulder<br>D2: Elbow<br>D3: Wrist |

Tailored combined exercise programs for various SCIs, including A type, B type, C type, and D type.

**Table 3** Description of the exercise program

| Characteristics | Components | Details | Duration |
|---|---|---|---|
| Exercise program | Warm-up | (1) Joint exercises (5 min)<br>(2) Arm ergometer exercises (15 min)<br>(3) Stretching (5 min) | 25 min |
| | Exercise | Development of combined exercise for SCI levels.<br>(1) Resistance training [1–3 sets, 10–20 reps]<br>*(a) Isometric neck exercise, (b) shoulder exercise (shoulder abduction, shoulder flexion, shoulder extension, shoulder press), (c) arm exercise (Elbow flexion, and extension), (d) chest exercise (chest press with machine or thera-band, shoulder horizontal adduction), (e) back exercise (seated row with thera-band, horizontal abduction with thera-band), (f) abdominal exercise (seated crunch, cat camel on wheelchair), (g) lower back exercise (trunk extension, lateral flexion), (h) rotator cuff exercise (shoulder internal & external rotations), (i) wrist and hand (finger flexion and extension, wrist flexion and extension, radial deviation and ulnar deviation, pronation and supination*<br>(2) Circuit training [1–2 sets, 10-s rest between intervals]<br>*Using resistance training programs for SCI levels (lateral raise, chest press, seated row with thera-band, trunk lateral flexion,* etc.*)*<br>(3) Aerobic training [10–20 min, 60–80 rpm]<br>*a) Arm ergometer or b)hand-cycle*<br>*Resistance exercise prescribed based on the level of injury<br>C4–C6: *a), b), c), e), h)*<br>C7 and C8: *a), b), c), e), h)*<br>T1–T6: *a), b), c), d), e), h), i)*<br>T7–L2: *a), b), c), d), e), f), g), h), i)* | 30 min |
| | Cooldown | Stretching | 5 min |
| Exercise intensity | Weeks | Borg scale | Intensity |
| | 1–2 weeks | Borg scale (RPE) rating 4–5 or max HR 65–70% | Moderate |
| | 2–4 weeks | Borg scale (RPE) rating 6–7 or max HR 75–80% | Moderate |
| | 4–6 weeks | Borg scale (RPE) rating 7–8 or max HR 80–85% | Vigorous |
| Exercise frequency | Exercise group*: total of 60 min, 3 times per week (Mon, Wed, Fri) for 6 weeks | | |

*SCI* spinal cord injury, *HR* heart rate

*Each exercise was supervised by certified trainers, who regularly monitored and adjusted exercise intensity

## Measurements

All measurements were obtained at baseline and after 6 weeks of exercise intervention. Venous blood samples were collected after a 12-h fast and analyzed for glucose (ADVIA 1650, Siemens, Tarrytown, NY, USA) and insulin (Roche, Indianapolis, IN, USA). Insulin resistance was estimated according to the homeostasis model assessment of insulin resistance (HOMA-IR) index [insulin (μIU/mL) × fasting glucose (mmol/L)/22.5] [17]. Total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) levels were measured using an ADVIA 1650 Chemistry System (Siemens, Tarrytown, NY, USA).

A handheld dynamometer (J-tech Medical Industries Inc., Salt Lake city, UT, USA) was used to measure upper body strength as previously described [18]. Briefly, the strength of shoulder flexors and extensors was measured in the supine position, with the shoulder and elbow flexed at 90°, the arm in a neutral rotation, and the dynamometer placed proximal to the humeral epicondyle. To measure the strength of the shoulder abductors and adductors, the dynamometer was placed proximal to the elbow, with the elbow fully extended and the shoulder abducted 45°, while the patient remained supine. The strength of elbow flexors and extensors was measured with the elbow flexed to 90° and the shoulder adducted to the trunk in the supine position.

Maximal graded exercise tests were performed using a ramp protocol. Patients were considered to reach $VO_2$ peak if two or more of the following three criteria were met: (1) HR peak of age-predicted maximum (220 minus chronological age); (2) $VO_2$ plateau with increasing exercise intensity; RER > 1.15; (3) an RPE of 19–20 [19, 20]. Oxygen consumption was measured using the True One 2400 Gas Analyzer (Parvo Medics, Sandy, UT, USA) while participants exercised with an arm ergometer.

Body composition was measured using a bioelectrical impedance analyzer (Inbody S10®, Seoul, Korea) while the subjects were supine. The bioelectrical impedance analyzer has been previously validated against dual energy X-ray absorptiometry, and the two techniques exhibit a correlation coefficient greater than 0.9 [21, 22]. Measurement of waist circumference (WC) was taken to the nearest millimeter in the supine position using a tape (Gullick II Tape Measure, Gays Mills, WI, USA) placed at the midpoint between the inferior portion of the lateral rib cage and the iliac crest.

## Statistical analysis

Statistical analysis was performed using SPSS, version 21.0 for Windows (SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to evaluate patient baseline characteristics. The primary analysis included all randomized participants based on the intention-to-treat (ITT) principle. Pre-training and post-training differences within each of the study groups were analyzed using Wilcoxon signed-rank tests. In addition, differences in clinical variables between the groups (exercise group vs. control group) were evaluated using the Wilcoxon rank-sum test to compare the pretest baseline values with the post-test values after 6 weeks of training. A linear mixed effect model was used to assess the impact of exercise the groups over time (i.e., group × time interaction; Tables 4 and 5). *P*-values less than 0.05 were considered statistically significant. Since we have two primary outcome measures, we applied Bonferroni correction for multiple testing.

# Results

## Participant characteristics

Seventeen individuals with SCI at injury level C4 to L1 participated in this study (Table 1). All participants completed 18 sessions of exercise program, and compliance rate to exercise program was 100% (Fig. 1). The mean participant age was 36.8 ± 6.9 years, and the mean body mass index (BMI) was 21.9 ± 2.82 kg/$m^2$.

## Primary outcome (effects of exercise on insulin and HOMA-IR)

Both fasting insulin (baseline: 7.5 ± 4.7 vs. post-intervention: 4.5 ± 2.2, $p = 0.004$) and HOMA-IR (baseline: 1.5 ± 1.0 vs. post-intervention: 0.9 ± 0.4, $p = 0.003$) were reduced in the exercise group, with no change in control group. Hence, the change in fasting insulin (mean difference, − 3.2 μU/ml; $p = 0.003$) and HOMA-IR (mean difference, − 0.66; $p = 0.001$) was significantly different in the exercise compared to the control group (Table 4). Consistent with this, there was a significant group x time interaction for insulin ($p = 0.047$), and HOMA-IR ($p = 0.048$).

## Secondary outcomes (effects of exercise on body composition, upper body muscle strength, and $VO_2$ peak)

The average WC (baseline: 84.1 ± 11.9 vs. post-intervention: 82.5 ± 11.4, $p < 0.05$), $VO_2$ peak (baseline: 11.7 ± 8.1 vs. post-intervention: 15.2 ± 9.6, $p < 0.05$), BMI, and percent body fat were significantly improved in the exercise group ($p < 0.05$). Compared to the controls, BMI, percent body fat, and $VO_2$ peak tended to be different at the end of combined exercise, although this tendency did not reach statistical significance (*p*-values ranged from 0.05 to 0.10) (Tables 4, 5). Upper body muscle strength, as measured by shoulder flexion, extension, abduction, and adduction, as well as elbow flexion and extension, were significantly increased after the exercise intervention ($p < 0.05$), with no change in control group. There was a significant difference in upper body muscle strength changes between the groups ($p < 0.05$), and a significant group x time interaction for WC ($p = 0.024$) and upper body muscle strength, supporting the beneficial effect of combined exercise program.

**Table 4** Changes in body composition, insulin and HOMA-IR

| | Exercise group ($n=11$) | | | Control group ($n=6$) | | | Δ$p$ value | *by linear mixed effect model $p$ value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | ΔPost–Pre | Pre | Post | ΔPost–Pre | | Group | Time | *Group*Time* |
| Body composition | | | | | | | | | | |
| BMI (m/kg$^2$) | 21.8 ± 2.9 | 21.3 ± 2.8* | −0.4 ± 0.2 | 20.8 ± 1.9 | 20.6 ± 2.0 | −0.1 ± 0.3 | 0.085 | 0.782 | 0.002 | 0.079 |
| Lean mass (kg) | 21.9 ± 5.2 | 22.0 ± 4.9 | 0.04 ± 0.9 | 19.3 ± 6.6 | 19.7 ± 7.0 | 0.4 ± 0.7 | 0.621 | 0.424 | 0.381 | 0.458 |
| Body fat (%) | 35.3 ± 10.8 | 33.5 ± 10.3* | −1.8 ± 2.0 | 39.6 ± 5.6 | 38.4 ± 7.1 | −1.2 ± 2.9 | 0.425 | 0.290 | 0.034 | 0.635 |
| WC (cm) | 84.1 ± 11.9 | 82.5 ± 11.4 | −2.6 ± 1.7 | 79.4 ± 6.6 | 79.2 ± 6.4 | −0.2 ± 0.4 | 0.015 | 0.567 | 0.005 | 0.024 |
| Cardiometabolic profiles | | | | | | | | | | |
| Glucose (mg/dl) | 81.0 ± 5.4 | 79.3 ± 5.4 | −1.6 ± 5.4 | 75.6 ± 3.6 | 77.5 ± 3.0 | 1.8 ± 5.5 | 0.284 | 0.097 | 0.945 | 0.232 |
| TC (mg/dl) | 162.3 ± 34.1 | 169.0 ± 25.5 | 6.6 ± 19.8 | 199.5 ± 34.0 | 213.8 ± 22.7 | 14.3 ± 19.6 | 0.512 | 0.012 | 0.054 | 0.455 |
| HDL-C (mg/dl) | 48.7 ± 21.3 | 54.3 ± 18.4* | 5.5 ± 8.0 | 51.2 ± 10.6 | 49.4 ± 10.6 | −1.7 ± 1.9 | 0.021 | 0.894 | 0.291 | 0.048 |
| LDL-C (mg/dl) | 93.5 ± 31.2 | 89.0 ± 27.0 | −4.5 ± 23.5 | 125.6 ± 29.3 | 139.6 ± 20.3 | 13.9 ± 19.5 | 0.228 | 0.006 | 0.419 | 0.122 |
| Insulin (μU/ml) | 7.5 ± 4.7 | 4.5 ± 2.2* | −2.9 ± 3.6 | 2.9 ± 1.1 | 3.2 ± 1.3 | 0.3 ± 0.4 | 0.003 | 0.054 | 0.098 | 0.047 |
| HOMA-IR | 1.5 ± 1.0 | 0.9 ± 0.4* | −0.6 ± 0.7 | 0.5 ± 0.2 | 0.6 ± 0.2 | 0.06 ± 0.06 | 0.001 | 0.053 | 0.102 | 0.048 |

Values are presented as mean ± SD

*BMI* body mass index, *WC* waist circumference, *TC* total cholesterol, *HDL-C* high-density lipoprotein cholesterol, *LDL-C* low-density lipoprotein cholesterol, *HOMA-IR* homeostasis model assessment-insulin resistance, *Pre* before training, *Post* 6 weeks after training

*$p < 0.05$

**Table 5** Changes in cardiopulmonary fitness and upper body muscle strength

| | Exercise group ($n=11$) | | | Control group ($n=6$) | | | $\Delta p$ value | *by linear mixed effect model $p$ value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | ΔPost–pre | Pre | Post | ΔPost–pre | | Group | Time | *Group*Time* |
| Cardiopulmonary Fitness | | | | | | | | | | |
| VO2 peak | | | | | | | | | | |
| (ml/kg/min) | 11.7 ± 8.1 | 15.2 ± 9.6* | 3.5 ± 2.4 | 9.4 ± 4.5 | 11.7 ± 7.9 | 2.3 ± 3.5 | 0.358 | 0.702 | 0.002 | 0.406 |
| Upper body muscle strength | | | | | | | | | | |
| EF (*N*) | 169.0 ± 73.0 | 231.0 ± 96.1* | 61.9 ± 32.5 | 202.8 ± 64.4 | 199.5 ± 68.5 | − 3.3 ± 12.9 | 0.001 | 0.978 | 0.001 | < 0.001 |
| EE (*N*) | 95.7 ± 81.9 | 128.6 ± 101.3* | 32.9 ± 26.3 | 94.5 ± 82.1 | 94.5 ± 87.9 | 0.0 ± 8.6 | 0.011 | 0.745 | 0.034 | 0.034 |
| SAB (*N*) | 118.7 ± 61.5 | 159.0 ± 71.3* | 40.3 ± 18.1 | 134.6 ± 60.7 | 135.0 ± 69.6 | 0.3 ± 18.1 | 0.002 | 0.904 | < 0.001 | 0.001 |
| SAD (*N*) | 124.3 ± 51.6 | 165.1 ± 65.2* | 40.8 ± 17.6 | 115.1 ± 69.3 | 116.3 ± 75.4 | 1.1 ± 7.3 | 0.001 | 0.393 | < 0.001 | < 0.001 |
| SF (*N*) | 120.0 ± 55.6 | 159.6 ± 68.4* | 39.6 ± 17.9 | 140.3 ± 67.0 | 141.1 ± 72.5 | 0.8 ± 8.3 | 0.001 | 0.978 | < 0.001 | < 0.001 |
| SE (*N*) | 128.6 ± 29.4 | 172.6 ± 38.8* | 44.0 ± 21.5 | 143.1 ± 71.0 | 144.8 ± 79.9 | 1.6 ± 12.7 | 0.002 | 0.810 | < 0.001 | 0.001 |

Values are presented as mean ± SD

$VO_2$ peak: peak oxygen consumption, *EF* elbow flexion, *EE* elbow extension, *SAB* shoulder abduction, *SAD* shoulder adduction, *SF* shoulder flexion, *SE* shoulder extension, *Pre* before training, *Post* 6 weeks after training

*$p < 0.05$

## Discussion

In this pilot study, we sought to investigate the effects of a 6-week combined exercise program on fasting insulin and fitness levels in those with SCI. We found that combined exercise program resulted in significantly reduced insulin levels and HOMA-IR levels. In addition, WC and percent body fat decreased and HDL-C levels, upper body muscle strength, and $VO_2$ peak increased in these participants.

Considering the increased risk of type 2 diabetes in those with SCI, ~ 40% decrease in both fasting insulin (38.6%) and HOMA-IR (40.0%) after the 6-week exercise program is important. A previous study that employed functional electrical stimulation (FES) cycling and rowing also found that fasting insulin level decreased after training [7]. In contrast to prior work, we included both aerobic and resistance exercises without FES. Although resistance exercise has been recommended for those with type 2 diabetes to improve glycemic control [23], there have been no studies including both aerobic and resistance exercises to reduce fasting insulin in those with SCI. Given our results, and the fact that SCI reduces skeletal muscle mass due to paralysis, including resistance exercise in an exercise program is important [24].

Individuals with an SCI frequently experience pain in the shoulder joints and may also exhibit rotator cuff impingement syndrome. Given that the upper extremities are used for most daily activities such as propelling wheelchairs and transferring [25], shoulder injuries can significantly reduce quality of life. Hicks et al. [26] reported that combined training significantly increased upper body muscle strength and reduced shoulder pain. Thus, strengthening the shoulder muscles may also reduce shoulder pain [27] (i.e., rotator cuff impingement syndrome and general shoulder pain). Previous studies have also reported significant improvements in muscle strength after FES cycling [28], rowing [29], arm ergometer [26], and hand-bike exercises [9] in individuals with SCI. The increased muscle strength of the shoulder flexors, extensors, abductors, and adductors we observed after 6 weeks of combined exercise is likely to improve scapular stability and shoulder strength, both of which are important to prevent shoulder problems in those with SCI.

We also found a 29.9% increase in $VO_2$ peak and a 34.2% increase in upper body muscle strength after the exercise program. These results are similar to those of Nash et al. [15], who found that circuit resistance exercise training improved muscle strength from 38.6% to 59.7% and $VO_2$ peak by 10.4% and reduced the extent of shoulder pain in middle-aged men with SCI. Jeon et al. [7] observed a significant increase in $VO_2$ peak after FES rowing training. In addition, Kim et al. [29] found an increase in $VO_2$ peak of 12.7% after FES rowing training in individuals with SCI. Improving cardiopulmonary fitness is important for people with SCI, since their relatively low level of cardiopulmonary fitness may lead to a reduced ability to perform daily life activities and may also leave them at an increased risk of developing type 2 diabetes and/or CVD [15, 30]. In the current study, while the change in $VO_2$ peak tended to differ between the groups (exercise vs standard care), the effect failed to reach the level of statistical significance set a priori ($p = 0.079$). This is likely due to the small number of individuals included in this pilot study.

Since remained muscle function is very limited in individuals with high lesion SCI (C4–C5), we have paid close attention as we progress with their exercise program. Knowing that all participants including high lesion cervical SCI were 100% compliant to prescribed exercise session, tailored exercise used in the current study was feasible regardless of level of SCI. Furthermore, when $VO_2$ peak change in response to exercise program was analyzed according to cervical and thoracic/lumbar SCI, we have noticed 41% (pre: 7.1 ± 2.8, post: 10.0 ± 3.9 ml/min/kg) increase in cervical SCI and 24.2% (pre: 18.6 ± 8.9, post: 23.12 ml/min/kg) increase in thoracic/lumbar SCI. Indeed, $VO_2$ peak as well as upper body muscle strength was improved in all participants in the exercise group including high lesion SCI (C4–C5). These results suggest that our tailored exercise program was effective to improve cardiopulmonary fitness as well as upper body muscle strength regardless of the level of SCI.

The main limitation of this pilot study was relatively small number of participants. Therefore, the generalization of the results of the current study needs caution. However, it was plausible that statistical significance in study outcomes was still observed even with small number of participants. Another limitation of the current study is potential carryover effect from the last bout of exercise on fasting insulin and HOMA-IR. Although there is no literature on the carryover effect of exercise on insulin sensitivity in people with SCI, the effect of last bout of exercise could last up to 48–72 h [31]. Therefore, we cannot differentiate whether significant reduction in fasting insulin and HOMA-RI are resulted from the last bout of exercise or chronic effect of 6 weeks of exercise training. The strength of the current study included application of individualized exercise program for individuals with SCI, which seems to be beneficial for metabolic and musculoskeletal health of participants. However, this study should be validated with future studies with larger sample size.

In conclusion, participating in a combined exercise program for 6 weeks was an effective strategy for reducing fasting insulin levels, reducing the HOMA-IR levels, and improving fitness in individuals with SCI.

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## Compliance with ethical standards

**Conflict of interest** No author has any conflict of interest.

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