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Effects of upper limb ergometer on pulmonary functions among spinal cord injury patients

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Abstract

Introduction. Spinal cord injury is a serious condition that has a profound impact on pulmonary functions and quality of life. Ergometer training is a form of fitness training that seems to influence cardiorespiratory fitness among young individuals. The objective of the study was to evaluate the effect of upper limb ergometry on pulmonary functions in thoracic spinal cord injury patients.

Methods. A randomised, parallel control trial was conducted by the lottery method. 44 patients (22 in each group), who had upper and lower thoracic spinal injuries, aged 25–45 years and of either sex were included. Patients were randomised into progressive upper limb ergometer training (group A) and conventional therapy (group B), and training was continued for six weeks. Outcomes were measured by using a spirometer for pulmonary function tests, assessed at baseline and each week.

Results. A total of 44 participants were analysed in which the mean age in group A was (35.77 ± 5.58) years and in group B was (32.27 ± 6.85) years. Mann–Whitney *U*-test was used for intergroup comparison of baseline to end values of (FEV1, PEF and FVC). FEV1 was significantly improved post-intervention (p-value = 0.008). Post-training PEF was significantly improved in both groups (p-value = 0.001). FVC was also significantly improved (p-value = 0.003) at the end of the sixth week.

Conclusion. The current study reports that upper limb ergometry has positive effects on spirometry values, as indicated by the improvements in the FVC, FEV1, and PEF values and pulmonary functions in thoracic spinal cord injury patients.

Key words: arm ergometry, forced expiratory volume in 1 s, peak expiratory flow, forced vital capacity, spinal cord injury, spirometry

Introduction

Spinal cord injuries (SCI) affect the personal and societal life of individuals, including young adults. Spinal cord injuries are divided into traumatic and non-traumatic, which have different aetiologies. Traumatic SCI is mostly caused by motor vehicle injuries, falls, and sports-related injuries. Non-traumatic injuries usually occur due to tumours, infections, and degenerative disc diseases [1]. In general, traumatic spinal cord injuries mostly occur at the cervical spine (60%), followed by the thoracic spine (32%) and lumbosacral spine (9%). A systemic review reported six million spinal cord injury survivors globally [2]. It has been found that men were more prone to develop SCI than women [3]. Spinal cord injuries greatly impact the life expectancy, quality of life, and economic burden of individuals. Traumatic injuries mostly occur in 15–29-year-olds. Spinal cord injury impairs the transmission of different impulses across the site of the lesion. In 2007, a prospective observational study was completed after a disaster occurred in Pakistan. It was the most cataclysmic natural disaster in the country's history and as a result, 73,000 people lost their lives and 126,000 were harmed, with most suffering spinal cord injuries. No registry was set up specifically for SCI, but according to different estimates, 650–750 were affected by SCI [4]. Different approaches have been introduced to assess different sensory and motor impairments related to different spinal cord injuries, including ASIA [5], the modified Frankel Scale, the Yale scale, the FIM scale and the Botsford Scale [6].

The leading cause of death in spinal cord injury patients is respiratory complications. Previous studies showed that cervical and upper thoracic spine injuries impair functions of respiratory muscles, determined by decreased spirometric values and lung volume parameters [7, 8]. It has been noted that thoracic spinal cord injury patients have an increased risk of developing respiratory complications, such as mucus retention, pneumonia, and a decline in total lung capacity [9]. Changes in chest wall compliance and decreased respiratory muscle strength also lead to abnormal changes in overall lung capacities. It has been suggested that pulmonary function is reduced in patients with SCI, which is also associated with higher BMI, low pulmonary muscle strength, and decreased physical activity [10] Training programs have shown tremendous benefits in cardiorespiratory fitness, cardiovascular fitness, metabolic fitness, and quality of life after SCI. Reconditioning training also enhances the lipid profile, improves the upper extremity muscle strength, lowers the risk of cardiovascular diseases, and reduces the incidence of osteoporosis [12, 13].

Various techniques, including assisted coughing, percussion, vibration, aspiration, and assisted postural drainage, are used to improve cardiorespiratory fitness levels [14]. Individuals with spinal cord injury have a low quality of life and low self-efficacy as compared to the general population [15]. The American College of Sports Medicine recommended various exercises with different frequencies for patients with paraplegia SCI, comprising different arm exercises such as arm cranking, wheelchair propulsion, swimming, wheelchair sports,

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and electrically stimulated walking. Various arm exercises had been shown safe and effective and also improve the overall cardiovascular function [16]. In a systemic review of upper limb functioning following cervical spinal injury, it was noticed that exercise training and electrotherapy played an important role in improving quality of life and upper limb disorders [17].

The literature states that passive leg cycling exercises and arm ergometry affect the peak oxygen uptake (VO_2max) in spinal cord injury patients [18]. A systematic analysis also showed the impact of clinical outcomes of upper limb training regarding fatigue, dyspnoea, and different upper limb functions [19]. Upper limb (UL) ergometry in incomplete SCI patients has a tremendous effect on enhancing aerobic capacity, overall mobility, and metabolic profiles [20]. Studies also supported that upper arm exercises have a beneficial effect on functional capacity in terms of VO_2peak in chronic SCI [21]. Systemic reviews have shown the scarcity of findings of upper limb training in spinal cord injury patients, while few studies have revealed the positive impact of upper limb training in patients with paraplegia [22]. Controlled breathing and upper limb exercises have a promising effect on cardiorespiratory function and exercise tolerance in SCI patients by improving the spirometric values and peak oxygen uptake [23, 24].

However, despite the widespread use of arm ergometry, there is little evidence in any systematic review to support its effects and benefits on pulmonary functions and overall cardiovascular fitness in subjects of different levels of SCI patients, thus leaving a gap in the scientific research. Therefore, this study was intended to evaluate the effect of upper limb ergometry on pulmonary functions in thoracic SCI patients.

Subjects and methods

Study design

A randomised, parallel controlled trial was conducted at Paraplegic Center, Hayatabad Peshawar, Pakistan. The sample size was calculated using an OpenEpi calculator with a 95% confidence interval (CI) [25].

Participants and randomisation

Randomisation was done using the lottery method. Patients who had upper and lower thoracic spinal injuries, aged 25–45 years and of either sex were included in the study [26, 27]. Out of 52 subjects, 44 patients met the inclusion criteria. Patients having any cardiovascular diseases, spinal malignancies, any active inflammation or infection, any psychiatric disorder, any neurological condition (stroke, Parkinson) or pressure ulcers (grade 3 and 4) were excluded [26].

The subjects were randomly divided in a 1:1 ratio into progressive upper limb (UL) ergometer training + conventional therapy (group A) and conventional therapy (group B) using a convenient sampling technique having ($n = 22$) patients in each group. Measurement was performed at baseline, and at the end of each week for six weeks in the Paraplegic Center, Hayatabad, using a semi-structured questionnaire. A physiotherapist with eight years of experience recorded physical therapy compliance and goal achievement within the prescribed treatment regime. The patients were unaware of the type of physical therapy received. One investigator assigned the participants to the groups while another physiotherapist implemented the treatment protocols. To ensure the precision of the intervention, the physiotherapist was fully skilled in implementing the designed treatment protocol. However, the investigators were unable to choose or control which patient received which physical therapy. The detailed treatment procedure was explained to the participants, along with the risks and benefits, and written informed consent was taken (Figure 1).

Outcome measures

Outcomes were measured by using spirometry. Spirometry is a basic, objective, noninvasive pulmonary function test [28]. Digital spirometry is used to measure the forced expiratory volume in one second (FEV1), forced vital capacity (FVC) and peak expiratory flow (PEF) [29]. A nose clip was applied to all patients to prevent the leakage of air from the nasal passages. A new, disposable mouthpiece was attached to the spirometer before testing each participant. It was ensured that

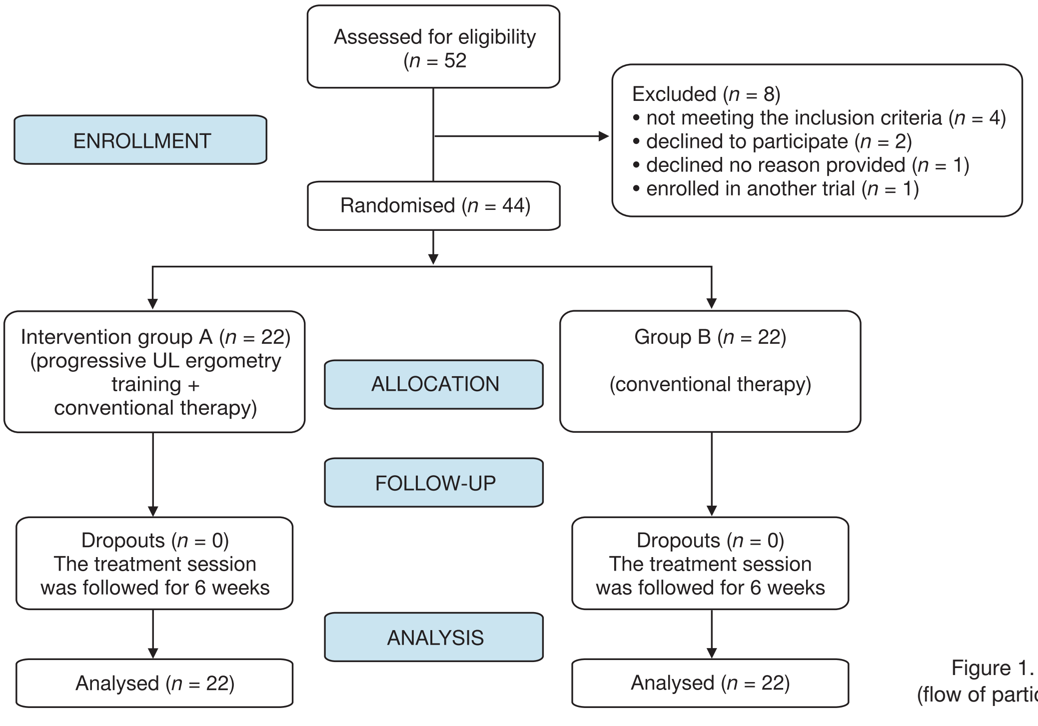

Figure 1. CONSORT diagram
(flow of participants through the trail)

subjects sealed their lips tightly around the mouthpiece and exhaled as hard and quickly as possible. The subject was actively encouraged during the procedure to exhale for as long as possible. Spirometry was performed in this way on patients of both groups before and after the training program.

Intervention

Intervention including progressive UL ergometer training + conventional therapy was given to group A, while only conventional therapy was given to group B.

Group A received Progressive UL ergometer training of 15 to 20 min twice a day for five days a week, along with conventional treatment. For measurements of the resting heart rate and blood pressure, the University of Toronto Arm Crank Protocol was used to assess heart rate/power output relationships at three submaximal workloads [30]. Subjects performed three sets for 5–7 min of steady-state workloads on a Monark™ arm ergometer at power outputs approximating 40%, 60%, and 80% of the predicted age-adjusted maximal heart rate [31].

Group B received conventional treatment, including deep breathing exercises: 10–15 repetitions twice a day, assistive coughing: 5–6 repetitions twice a day [32], sustained stretching, splinting, bracing, ROM exercises [33], tilt table standing [34] and functional mobility exercises [35] i.e.; (two sessions/day; five days/week). Treatment sessions were given for six consecutive weeks to each participant.

Statistical analysis

Data was collected on the first and sixth day of each week by using a semi-structured questionnaire. Prior to performing the spirometry, the patient's height, weight, age, and sex were recorded (68). The data were analysed at baseline and at six weeks of intervention using IBM SPSS 24 (Statistical Package for Social Sciences) and presented as tables. Descriptive analysis was performed for the demographic variables. When the test of normality was applied to the data, it was shown that the data was not normally distributed for FEV1, FVC and PEF as the p-value was less than 0.05 at 95% confidence interval, so a non-parametric test was applied using Mann–Whitney to compare the pre- and post-training from week 1 to week 6 between both groups.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Internal Review Board (IRB) of Riphah College of Rehabilitation and Allied Health Sciences, Riphah International University, Islamabad (approval No.: Riphah/RCRS/REC/00592).

Informed consent

The detailed treatment procedure was explained to the participants, along with the risks and benefits, and written informed consent was taken.

Results

A total of 44 participants were analysed in which the mean age in the progressive UL ergometer training group was (35.77 ± 5.58) years and in the conventional therapy group was (32.27 ± 6.85) years. A comparison between the groups implied a normal demographic distribution. In the progressive UL ergometer training group, 36.4% were females and 63.6% were males, while in the conventional therapy group, 22.7% were females and 77.3% were males.

Intergroup comparison of the baseline to end values was done with the Mann–Whitney *U*-test for FEV1. In week 1, the baseline (pre-training), mean ± *SD* in the progressive UL ergometer training group was (47.73 ± 21.64) and in the conventional therapy group was (50.19 ± 19.46), being insignificant ($p > 0.05$). FEV1 was significantly improved at post-intervention (*p*-value = 0.008) with a mean ± *SD* in the progressive UL ergometer training group of (76.50 ± 18.47) and in the conventional therapy group of (62.23 ± 15.57) at the end of the sixth week (Table 1).

Table 1. Intergroup comparison of FEV1 from week 1 to week 6

Variable FEV1 in percentage		Interventional group (mean ± *SD*)	Control group (mean ± *SD*)	*p*-value
Week 1	pre-training	47.73 ± 21.64	50.19 ± 19.46	0.694
	post-training	46.05 ± 20.14	55.37 ± 14.91	0.089
Week 2	pre-training	50.41 ± 15.13	55.46 ± 15.62	0.283
	post-training	53.27 ± 8.84	54.31 ± 17.83	0.851
Week 3	pre-training	59.45 ± 18.37	56.50 ± 15.35	0.566
	post-training	64.55 ± 16.78	55.59 ± 16.78	0.064
Week 4	pre-training	65.86 ± 16.50	57.46 ± 16.59	0.099
	post-training	65.73 ± 17.12	58.09 ± 15.50	0.129
Week 5	pre-training	68.55 ± 19.42	58.36 ± 19.32	0.089
	post-training	69.68 ± 16.89	56.68 ± 18.64	0.020*
Week 6	pre-training	68.45 ± 15.37	62.09 ± 13.12	0.147
	post-training	76.50 ± 18.47	62.23 ± 15.57	0.008*

FEV1 – forced expiratory volume in 1 second
* statistically significant difference ($p < 0.05$)

Table 2. Mann–Whitney *U*-test was applied for between-group analysis of PEF from week 1 to week 6

Variable PEF in percentage		Interventional group (mean ± *SD*)	Control group (mean ± *SD*)	*p*-value	*Z*-value
Week 1	pre-training	32.73 ± 17.70	35.09 ± 19.48	0.676	–0.023
	post-training	33.77 ± 19.69	34.77 ± 16.47	0.856	–0.212
Week 2	pre-training	32.32 ± 17.09	36.09 ± 17.00	0.467	–0.839
	post-training	31.96 ± 16.13	41.09 ± 23.66	0.143	–1.645
Week 3	pre-training	34.73 ± 11.08	32.64 ± 9.58	0.507	–0.764
	post-training	38.00 ± 10.81	32.14 ± 8.29	0.050	–2.203
Week 4	pre-training	40.50 ± 16.56	32.41 ± 32.41	0.048*	–1.787
	post-training	35.27 ± 7.98	35.18 ± 16.71	0.982	–1.223
Week 5	pre-training	38.64 ± 9.81	34.41 ± 7.90	0.123	–1.659
	post-training	43.55 ± 17.71	34.32 ± 8.58	0.036*	–2.374
Week 6	pre-training	41.09 ± 11.22	35.64 ± 10.10	0.098	–1.563
	post-training	45.45 ± 12.72	33.68 ± 9.85	0.001*	–3.007

PEF – peak expiratory flow
* statistically significant difference ($p < 0.05$)

Table 3. Intergroup comparison of FVC from week 1 to week 6

Variable FVC in percentage		Interventional group (mean ± *SD*)	Control group (mean ± *SD*)	*p*-value	*Z*-value
Week 1	pre-training	51.09 ± 21.91	42.50 ± 15.90	0.981	–0.023
	post-training	46.23 ± 18.05	50.64 ± 14.90	0.832	–0.212
Week 2	pre-training	51.41 ± 17.51	49.68 ± 15.15	0.372	–0.893
	post-training	51.36 ± 17.73	50.68 ± 18.42	0.100	–1.645
Week 3	pre-training	55.32 ± 15.25	51.59 ± 14.58	0.445	–0.764
	post-training	57.18 ± 13.52	54.18 ± 18.180	0.028*	–2.203
Week 4	pre-training	60.77 ± 17.49	52.00 ± 15.51	0.074	–1.787
	post-training	61.50 ± 16.77	51.73 ± 13.84	0.221	–1.223
Week 5	pre-training	65.32 ± 14.50	57.91 ± 13.09	0.097	–1.659
	post-training	65.59 ± 12.97	57.05 ± 14.60	0.018*	–2.374
Week 6	pre-training	64.09 ± 14.15	55.00 ± 14.47	0.118	–1.563
	post-training	72.18 ± 13.65	56.91 ± 13.99	0.003*	–3.007

FVC – forced vital capacity
* statistically significant difference ($p < 0.05$)

Between-group analysis for PEF was done with the Mann–Whitney *U*-test. In the first week, the pre-training (baseline), mean ± *SD* for PEF in the progressive UL ergometer training group was (32.73 ± 17.70) and in the conventional therapy group was (35.09 ± 19.48), which was insignificant with $p > 0.05$. The post-training PEF was significantly improved in both groups at the end of the sixth week with (p-value = 0.001), having a mean ± *SD* for PEF in the progressive UL ergometer training group of (45.45 ± 12.72) while in the conventional therapy group of (33.68 ± 9.85) (Table 2).

The Mann–Whitney *U*-test was used for the between-group analysis. FVC was significantly improved (p-value = 0.003) on the sixth week, with the post-intervention having a z value of –3.007 (Table 3).

Discussion

The study intended to evaluate the effect of upper limb ergometry on pulmonary function by using an arm ergometer against conservative treatment for thoracic spinal cord injury patients. The primary outcome of this study was testing of pulmonary functions, which were measured by using a digital spirometer. The literature review revealed that clinical trials are needed since there is a dearth of clinical trials on the technique of upper limb ergometry among thoracic spinal cord injury patients in Pakistan. The findings of the intergroup analysis showed both groups yielded improvement in PEF, FVC and FEV1, but the interventional group receiving progressive UL ergometer training showed marked promising effects by improving their PEF, FVC and FEV1 values.

Results of some previous clinical trials in which different combinations of techniques were used are in line with this study in terms of improvement of the PEF, FVC and FEV1 values.

A study held by Battikha et al. [36], in which arm ergometry was used, included 20 complete spinal cord injury male patients, to evaluate impaired pulmonary function. Respiratory parameters were measured by a spirometer. The study concluded that exercise capacity has a significant impact on respiratory capacity. Outcomes of this study correlate with the findings of our study in which upper arm ergometry produces potential benefits by improving forced vital capacity and forced expiratory volume in one sec. The same findings were observed in the latest study conducted by Brizuela et al. [37], in which an arm-crank exercise training program was used, which showed effective results on exercise performance and pulmonary function parameters in quadriplegic spinal cord injury patients. The results of our study can be confirmed by the outcomes of previous studies by Verellen et al. [38], Rosly et al. [28] and other researchers.

Another study reported the effectiveness of wheelchair-specific arm ergometry on cardiorespiratory parameters in 7 male SCI patients, and the sessions were given for 3 times a week for 6 weeks. This study supports the current study, in which an arm ergometry helped to improve the cardiorespiratory functions and overall fitness level [39]. The same findings were observed in a study conducted using the combination of a treadmill training and arm ergometry and results showed significant improvement in the spirometric values, which supports the current study [40].

A study conducted by Akkurt et al. [41] identified the effects of upper extremity aerobic exercise utilising an arm ergometer in patients with spinal cord injury. Arm ergometer exercises (three days/week) and general exercises (two sessions/day), were given for 12 weeks and pulmonary functions (FEV1%, FVC%, FEV1/FVC%) were assessed by the spirometer. The outcomes achieved by this study are quite similar to our clinical trial, in which improvement in the lung function test were observed.

The systemic review performed by Alajam et al. [42] on the effect of various Treadmill exercises, using upper limb arm ergometer, showed that these training approaches have a moderate effect in individuals with SCI in improving cardiovascular and pulmonary health. While recent trial presented a major improvement in pulmonary function test.

Limitations

The current study has some limitations. The first is the relatively small sample size. In addition, only short-term effects of the combination of treatments were assessed on thoracic spinal cord injury patients due to a lack of funds and patients' poor compliance with the twice daily training sessions. Therefore, the above-mentioned shortcomings should be addressed by conducting a study with a longer follow-up duration (12-week follow-up) with a large sample size by using advanced objective tools and also by including other spinal injuries levels.

Conclusions

The presence of respiratory complications in spinal cord injury patients is a common source of decline in pulmonary functions tests. The current study reports that upper limb ergometry has positive effects on spirometry values, which indicates the improvements in FVC, FEV1 and PEF values along with the improvements of pulmonary functions. Therefore, upper limb ergometry intervention should be combined with conventional physical therapy treatment regimes in the treatment of thoracic spinal cord injury patients.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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