The effect of trunk support on performance during arm ergometry in patients with cervical cord injuries

B Klefbeck^{1,2}, E Mattsson¹ and J Weinberg²

Departments of ¹Physical Therapy and ²Neurology, Söder Hospital, Karolinska Institute, Stockholm, Sweden

Earlier studies have shown that the diaphragm might have a postural function that could interfere with its respiratory function during arm cycling in patients with cervical cord injuries with impaired elbow extension. The purpose of this study was to evaluate the effect of trunk support on working performance in such patients. Ten patients with low-cervical-cord injuries performed an arm ergometer test without and with trunk support with at least one week between the tests. The work load averaged 30 (20–50) Watt. Oxygen uptake at steady state averaged 0.71 ± 0.09 l/min without trunk support and 0.64 ± 0.10 l/min with trunk support, $P < 0.05$. There was no difference in blood lactate without or with trunk support. Maximum performance time averaged 8.3 ± 4.3 min without trunk support and 19.5 ± 8.8 min with trunk support, $P < 0.01$. Oxygen saturation tended to decrease during work and returned to resting values after termination. This study showed that trunk support during arm ergometry in cervical-cord-injury patients with impaired elbow extension decreased the energy cost during sub-maximal work and increased the time to perform work. The results indicate that trunk stabilisation might improve performance of activities of daily living and that it should also be considered during exercise affecting the postural balance of these patients.

Keywords: tetraplegia; arm ergometry; diaphragm; trunk support; oxygen uptake

Introduction

In patients with a complete low-cervical-cord injury, physical work capacity is reduced due to impaired muscle function.^{1,2} Respiratory function is also reduced since supraspinal control of respiratory muscles innervated from spinal segments situated below the lesion has been eliminated. As well as skeletal muscle paralysis, these individuals have impaired responses through the autonomic nervous system. As a consequence, arm exercise will not activate the sympathetic nervous system as in normals.² The trunk muscle paresis leads to impaired trunk stability and respiratory function, and cervical cord-injury (CCI) patients are therefore highly dependent on their diaphragmatic function.

During arm ergometry in CCI patients with poor triceps function (unable to lift the forearm against gravity, less than 3 on a 0–5 scale³) the rotation of the handles is achieved only with arm flexion. Each pull of the handle will pull the trunk forward owing to the absence of voluntary trunk muscle function and inability to compensate for the forward position by extending the elbow. Sinderby *et al*⁴ found that CCI patients with poor triceps function during arm ergometry changed breathing patterns and increased abdominal pressures. The change was accompanied by

continuous diaphragm activity as indicated by electromyography (EMG). In CCI patients leaning forward at rest Sinderby *et al*⁵ found changes in abdominal pressure and continuous EMG diaphragm activity similar to those found during arm ergometry. These authors concluded that the diaphragm had a postural function in CCI patients. They also compared abdominal pressures and EMG patterns during arm ergometry between patients with triceps function and those without and found that the latter had abdominal pressures resembling those of CCI patients leaning forward and with similar diaphragmatic EMG patterns.

Arm cranking and wheelchair ergometry are the two modes of upper-body exercise that are most frequently employed to assess the working performance of tetraplegic patients^{1,2,6,7,8}. Some studies of the effect of arm ergometry training on tetraplegic patients^{6,7,8} show that the training increased maximal oxygen uptake, and increased physical work capacity. In these reports the subjects sat in their own wheelchairs but neither the function of the triceps nor the use of trunk support was mentioned.

Some tetraplegic patients in athlete wheelchair training fix themselves with their legs flexed up towards the body and in quad rugby they fix their chests to the wheelchairs with straps to make up for possible impairment of trunk stability. They consider

that this sitting position improves their balance and is more effective for these sports. In the present study we have chosen the unskilled task of arm ergometry to be able to assess tetraplegic patients independently of their different mechanical efficiency of wheelchair propulsion. This is thought to be a good method for both trained and untrained tetraplegic individuals. The purpose was to evaluate the effect of trunk support on working performance in CCI patients with impaired elbow extension during arm ergometry.

Patients

The criteria for participation were a complete traumatic low-cervical-cord injury of more than 1 year's duration, with elbow-extension function of less than 3 and elbow flexion function of more than 3 on a 0–5-grade scale for assessing the strength of weak muscles.³ The patients had to have either clinically complete upper motor neuron lesions without preserved motor or sensory function (Frankel classification A), or absence of motor function below the level of the lesion, but some preserved sensation (Frankel Classification B).⁹ The patients also had to be free of cardiorespiratory diseases and able to perform work of at least 20 Watt (W) on an arm ergometer. Sixteen tetraplegic patients from training centres and meeting clubs for handicapped people in Stockholm fulfilled the first criterion, but only 10 of them managed 20 W arm cycling. All 10 patients (nine male, one female) gave their informed consent prior to participation. The patients had injuries at levels C5 to C6. Mean age was 31 (range 21–41) years and mean duration of injury was 10.6 (range 1.3–24) years. All experienced occasional spasm in the afflicted muscles. Four of the patients were smokers. Individual data are given in Table 1.

Methods

The patients came to the clinic three times for arm ergometer tests with at least a week between each

test. A pre-test was followed by two tests (tests 2 and 3) in which the patients arm-cycled with and without trunk support. Before the tests the bladder was emptied.

Pre-test

The pre-test was performed to find the highest workload the patients could maintain for 4 min. The patients were tested while sitting in their own wheelchairs without trunk support. As they had no grip function, special gloves were used to fix their hands to the hand-grips. As a preparation for tests 2 and 3 the patients practised breathing through a mouthpiece and wore a nose clip to avoid breathing through the nose. An arm ergometer with an electrical brake was used (RE 820, Rodby Innovation AB, Södertälje, Sweden). The crank was adjusted so the highest point of the hand-grips was at shoulder level. The crank rate was 60 per min and the initial work load of 20 W was increased every 4th min in 10-W steps to the maximum tolerated load.

Test 2 and 3

The work loads during tests 2 and 3 were the highest the patients could maintain for 4 min during the pre-test. For test 2 or 3, selected at random, the patients had a trunk support consisting of a firm extended back support fixed to the back of the wheelchair. To this extended support the patient was secured with a belt round the thorax leaving the abdomen free. The belt did not interfere with arm and scapula movements.

The patients warmed up for 6 min at a lower load than the test load. If the work load was 20 W the warm up was at 20 W with manual cranking help from the test leader. The patients then cranked for 4 min. This was followed by a rest period of 5 min, after which the patients were encouraged to crank for as long as they could. After 30 min the test was stopped.

Heart rate was recorded using an electrocardiogram recorder (Mingograf 61, Siemens-Elcoma, Solna, Sweden). Leads were placed on the trapezius (where

Table 1 The patient's gender, age, level of spinal cord injury, time elapsed since injury, Frankel scale and numbers of cigarettes smoked daily

Patient	Sex	Age (years)	Level of injury	Time (years)	Frankel class	Cigarettes (number) daily
1	Male	41	C5	24.0	B	10
2	Male	27	C6	6.0	A	0
3	Female	23	C6	2.0	A	0
4	Male	39	C6	19.0	B	0
5	Male	33	C5, C6	13.0	A	20
6	Male	40	C5, C6	22.0	A	14–15
7	Male	37	C5, C6	8.0	A	0
8	Male	22	C5, C6	1.3	A	0
9	Male	21	C6	2.1	B	0
10	Male	27	C5	6.0	B	10

they would not interfere with arm movements) and on the medial part of the ankles. Respiration rate was measured visually by the test leader for the last 15 sec of every min.

Blood pressure was measured using an arm model before work started, after 4 min cranking, and on termination of work.

Oxygen uptake

Oxygen uptake was determined using a method with high accuracy.¹⁰ During the test, the patients breathed through a mouthpiece connected to a mixing box (volume 10 litres) by a flexible low-resistance hose. The mixing box was placed as close as possible to the patient without interfering with arm movements. Small movements of the head were allowed by a flexible joint near the mouth. Argon gas with a constant well-defined flow was added to the inlet of the box to determine the ventilation. The box was closed after 6 min of rest, at the end of 4 min of work, and on termination of work. A sample of the gas mixture from the box was aspirated into labelled 100 ml glass syringes after each occasion. The gas mixture was subsequently analysed with a respiratory mass spectrometer (MGA 2000, Air Spec Ltd, UK). Ventilation, oxygen uptake and carbon dioxide elimination were calculated following the method of Linnarsson *et al.*¹⁰

Blood lactate

Capillary fingertip blood was sampled at rest, after 4 min of work and on termination of work. The samples were frozen and subsequently analysed according to the hospital routine.

Oxygen saturation

Oxygen saturation (SaO₂) was recorded continuously with an oximeter (OXI, Radiometer A/S, Copenhagen, Denmark) which is reliable for values above 75%.¹¹ The oximeter used in this study was validated via arterial blood sampling and connected to the ear lobe with an ear probe. Prior to attachment, the lobe was rubbed with isopropyl alcohol to increase perfusion. To reduce motion artefacts, the probe was taped to the ear. Electrical output from the oximeter was recorded continuously (paper speed 10 mm/min).

Perceived exertion

Perceived exertion in the arms and of breathing was rated by the patients at the end of 4 min of work, and on termination, using the Borg category scale for ratings of perceived exertion (graded 6–20).¹²

Statistical methods

Values are presented as mean, standard deviation (SD), median and range. Wilcoxon's signed rank test was used for analyses of the parameters of the group. The Spearman rank-order correlation coefficient was used for analyses of correlation. A probability of less than 0.05 was considered significant.

The study was approved by the Ethical Committee at the hospital.

Results

Work load ranged between 20 W and 50 W (Table 2). Oxygen uptake averaged 0.25 ± 0.03 (mean $\pm$ SD) l/min at rest. This corresponds to the values for healthy, uninjured persons i.e. 0.2 to 0.3 l/min.¹³

Table 2 Arm ergometry without and with trunk support

Patient	Work (Watt)	Without trunk support					With trunk support				
		Steady state Oxygen uptake (l/min)	Blood lactate (mmol/l)	Time (min)	End of work Oxygen uptake (l/min)	Blood lactate (mmol/l)	Steady state Oxygen uptake (l/min)	Blood lactate (mmol/l)	Time (min)	End of work Oxygen uptake (l/min)	Blood lactate (mmol/l)
1	20	0.65	3.9	10.3	0.76	4.6	0.66	4.3	15.4	0.65	3.8
2	40	0.73	1.9	4.5	0.54	2.6	0.59	2.3	30.0	0.58	1.4
3	30	0.61	3.7	8.0	0.53	3.2	0.51	3.9	16.0	0.56	3.1
4	40	0.80	1.6	11.0	1.03	2.2	0.67	2.9	23.8	0.61	3.0
5	30	0.75	4.5	16.0	0.67	3.3	0.59	4.6	16.0	0.78	4.4
6	50	0.85	5.3	5.0	0.82	4.8	0.73	4.3	16.4	0.82	3.3
7	50	0.79	4.8	3.8	0.87	4.7	0.86	6.1	3.7	1.12	5.4
8	30	0.65	2.3	11.1	0.55	1.3	0.59	1.9	30.0	0.59	1.6
9	30	0.61	2.6	10.8	0.56	3.7	0.58	3.1	13.2	0.44	3.0
10	30	—	—	2.3	—	—	—	—	30.0	—	—
Mean	35	0.71	3.4	8.3	0.70	3.4	0.64	3.7	19.5	0.68	3.2
SD	9.7	0.09	1.3	4.3	0.18	1.2	0.10	1.3	8.8	0.20	1.3
							*	n.s.	*	n.s.	n.s.

Analyses of differences between without and with trunk support are presented. * = $P < 0.05$, n.s. = not significant, — = missing values

Oxygen uptake after 4 min work without trunk support averaged 0.71 ± 0.09 l/min and the corresponding value with trunk support averaged 0.64 ± 0.10 l/min ($P < 0.05$). There were no significant differences between oxygen uptake on termination of work without trunk support (0.70 ± 0.18 l/min) and on termination with trunk support (0.68 ± 0.20 l/min). Two patients (nos 5, 7) had an increased spasticity with a synchronous increase in oxygen uptake at the end of work with trunk support. Individual data are given in Table 2.

Blood lactate averaged 2.4 ± 1.5 mmol/l at rest. In a healthy uninjured person the blood lactate concentration at rest is reported as one mmol/l.¹³ Blood lactate averaged 3.4 ± 1.3 mmol/l after 4 min work without trunk support and 3.7 ± 1.3 mmol/l after 4 min work with trunk support. Corresponding values on termination of work were 3.4 ± 1.2 mmol/l and 3.2 ± 1.3 mmol/l. No significant differences were seen between working without trunk support and working with trunk support. Individual data are given in Table 2.

Maximal performance time without trunk support averaged 8.3 ± 4.3 min and with trunk support 19.5 ± 8.8 min ($P < 0.01$). For seven patients the reasons for stopping work without trunk support were related to perceived arm exertion, and for the rest (nos 2, 4, 10) to breathing exertion. Reasons for stopping work with trunk support were for five patients (nos 1, 3, 5, 6, 7) perceived arm exertion, while two patients (nos 4, 9) stopped the test because of breathing exertion and three were stopped by the test leader after 30 min. Individual data are given in Table 2.

The median of perceived arm exertion after 4 min was 16 (range 9–19) without trunk support and 16 (range 7–18) with trunk support. On termination of work, median perceived arm exertion was 18 (range 15–20) without trunk support and 17 (range 14–20) with trunk support. The median of perceived breathing exertion after 4 min was 15 (range 9–17) without trunk support and 15 (range 9–16) with trunk support. On termination of work, median perceived breathing exertion was 17 (range 11–20) without trunk support and 16 (range 9–19) with trunk support.

Oxygen saturation at rest averaged $95.8 \pm 2.3\%$. The minimum SaO_2 during work without trunk support averaged $87.9 \pm 5.3\%$ and during work with trunk support $92.0 \pm 4.8\%$. One and two min after work without trunk support, SaO_2 averaged $94.9 \pm 3.1\%$ and $95.7 \pm 3.1\%$, respectively. The corresponding values with trunk support were $94.3 \pm 2.3\%$ and $94.6 \pm 2.2\%$. SaO_2 decreased significantly from resting values during work both without and with trunk support ($P < 0.001$).

Heart rate (HR) at rest averaged 65 ± 12 beats per min (bpm). After 4 min of work HR averaged 100 ± 13 bpm without trunk support and 102 ± 12 bpm with trunk support. On termination of work HR averaged 103 ± 14 bpm without trunk support and 106 ± 13 bpm with trunk support.

Respiration rate at rest averaged 16 ± 3 breaths per

min. After 4 min of work, it averaged 24 ± 5 breaths per min without trunk support and 25 ± 4 breaths per min with trunk support. On termination of the work, it averaged 27 ± 5 breaths per min without trunk support and 25 ± 5 breaths per min with trunk support.

Blood pressure values at rest averaged 103/67 (systolic/diastolic) $\pm 12/9$ mmHg. After 4 min of work, blood pressure averaged 103/69 $\pm 13/9$ mmHg without trunk support and 111/71 $\pm 17/10$ mmHg with trunk support. Seven patients increased 0–5 mmHg in systolic pressure and 3 patients (nos 4, 8, 10) increased 10–20 mmHg in systolic pressure. On termination of work, blood pressure averaged 104/69 $\pm 20/10$ mmHg without trunk support and 111/71 $\pm 26/12$ mmHg with trunk support. Six patients increased 0–5 mmHg in systolic pressure and 3 patients (nos 1, 4, 5) increased 10–50 mmHg and patient no 7 decreased 30 mmHg in systolic pressure.

Discussion

The criterion for participating in this study was that the patients should be able to perform work of least 20 W. This work load was chosen as a lower participating limit, because most of the activities of daily life and sport activities require at least 20 W.¹³ Most of the participants were involved in physical training and all of them were interested in obtaining more knowledge of their physiological responses to training activities with trunk support for activities of daily living and/or sports. The work load chosen in this study was a sub-maximal load as close as possible to the patient's maximal capacity. This work load was also chosen as it could be a sufficiently effective load for these patients to receive a favourable effect of training. Training close to maximal oxygen uptake is recommended to increase work capacity.¹³

Sinderby *et al* reported that the diaphragm has a postural function when tetraplegic patients fall forward during arm cycling. They also noted a change in the breathing pattern and increased abdominal pressure during the forward fall.⁴ The trunk support in the present study was designed to prevent the patients from falling forward during arm cranking. The trunk support was attached to the wheelchair to get as realistic and useful trunk support as possible, considering the postural findings of Sinderby *et al* mentioned above. Thus the decreased oxygen uptake seen in the present study might reflect an unloading of the diaphragm. It is not possible from the data in the present study to evaluate whether biomechanical and kinesiological effects, due to a possibly more favourable mechanical situation, may to some part contribute to the reduced oxygen cost and prolonged performance time when trunk support is used. The lack of difference in perceived exertion indicates that there was no difference of work in the arm muscles.

Wicks *et al*¹⁴ compared maximal wheelchair performance and arm cranking in seven subjects, two being normal males, three paraplegic and two tetraplegic patients. They found no differences in oxygen uptake and whether trunk stability would have an effect on oxygen uptake in the small numbers of subjects in their study remains uncertain. This suggests that impaired trunk stability did not affect the efficiency of arm cranking providing that upper limb function was relatively normal. This contrasted with the patients in the present study whose elbow extension impairment explained effect of trunk support on performance.

Muscle spasticity might explain the high values of capillary blood lactate at rest compared to lactate levels in normals. Since there were no differences in blood lactate levels between work without trunk support and work with, the measured decrease of oxygen uptake with trunk support implies a decrease in total energy consumption. Two patients, probably due to spasticity, did not increase their performance time neither did they decrease their oxygen uptake during work with trunk support as seen in the others. Despite including these patients the mean change of these variables was significant. During the tests we did not observe any further spasticity problems interfering with the performance.

Values of SaO₂ using pulse oximetry compared to values of arterial blood gas samples have been questioned. Mangelkoch *et al*¹⁵ reported in a review article that most studies showed that pulse oximeter estimates during exercise were accurate predictors of arterial SaO₂, if SaO₂ values exceeded 85% in nonsmokers. In our study SaO₂ was mainly above 85%, but four patients were smokers (Table 1) and consequently the observed SaO₂ could be falsely high for these patients.^{13,16}

It is notable that the patients did not perceive the significant decrease in SaO₂ during work. Gottfried *et al*¹⁷ and Sinderby *et al*¹⁸ have reported that the perception of strenuous breathing in CCI patients may be reduced. According to Sinderby *et al*, afferent information seems vital for an adequate response to fatiguing load and they found EMG signs of diaphragmatic fatigue in CCI patients arm cranking. In the present study more than half of the patients stopped because of exertion perceived in the arms and not because of a sensation of breathing exertion, implying that they were less aware of SaO₂ desaturation and of the probably large diaphragmatic load. The reduced energy cost while exercising with trunk support might imply that the CCI patient will benefit from the use of trunk support in activities that affect their postural balance. This improves the ability to strengthen uninjured muscles and might also facilitate improved physiological performance in a larger perspective.

Conclusions

This study showed that trunk support during arm ergometry in CCI patients with impaired elbow extension decreased the energy cost during sub-maximal work and increased the time to perform work. The decrease of energy cost might reflect a decrease of the work load on the diaphragm. The results indicate that trunk stabilisation might improve performance of activities of daily living and should be considered during exercise affecting the postural balance of these patients.

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