Original article

Assessment of the ability of wheelchair subjects with spinal cord injury to perform a specific protocol of shoulder training: a pilot study

Giovanni Merolla[1,2]
Fabio Dellabiancia[2]
Maria Vittoria Filippi[3]
Elisa De Santis[2,4]
Daniele Alpi[2]
Paola Magrini[2]
Giuseppe Porcellini[1]

[1] Unit of Shoulder and Elbow Surgery, D. Cervesi Hospital, Cattolica, AUSL della Romagna Ambito Territoriale di Rimini, Italy
[2] Biomechanics laboratory "Marco Simoncelli", D. Cervesi Hospital, Cattolica, della Romagna Ambito Territoriale di Rimini, Italy
[3] Service of Functional Recovery and Rehabilitation, AUSL della Romagna Ambito Territoriale di Rimini, Italy
[4] ShoulderTeam Rehabilitative Office, Forlì, Italy

Correspondig author:
Giovanni Merolla
Unit of Shoulder and Elbow Surgery
D. Cervesi Hospital
Via L. V. Beethoven, 1
47841 Cattolica, Italy
E-mail: giovannimerolla@hotmail.com

Summary

***Background*: a regular program of exercises in subjects with spinal cord injury (SCI) can contribute to reduce the risk of upper extremities injuries. *Methods*: in this prospective laboratory study we tested the hypothesis that a training machine developed for able-body users is suitable for a shoulder training protocol in 11 paraplegic subjects with SCI. Overall subjects were assessed with the SCIM III, CS, DASH and standard shoulder examination. We set a protocol of shoulder exercises performed with a training machine. Overall subjects were able to perform the protocol but 2 did not complete the exercises n° 6 and 7. The position of the wheelchair during each exercise was recorded. Wheelchair position/loading level were significantly correlated with the protocol n° 2, 3 and 5 as well as BMI/loading level for the exercises n° 5 and 9 and age/loading level for the exercise n° 7. Clinical scores were neither correlated with loading nor with anthropometric data. *Results/Conclusions*: from the analysis of data collected in this study arised that: 1) the training machine needs some adjustments for paraplegic subjects, 2) the training protocol was appropriate except for the exercises needing a torso-rotation and 3) the template for wheelchair position may be a valid guide for an optimal paraplegic shoulder training.**

KEY WORDS: exercise, shoulder, spinal cord injury, training, wheelchair.

Introduction

Epidemiological survey from USA reports about 11000 acute spinal cord injuries (SCI) each year[1], and a considerable number of the affected patients makes use of manual wheelchair (WC) as a mean of deambulation that increases the stability and mobility demands on the upper limbs. This continous overuse of the gleno-humeral joint and overload on the rotator cuff (RC), otherwise known as "weight bearing shoulder"[2], contributes to the upper extremity pain and injury. A satisfactory shoulder function in persons with SCI is essential as for activities of daily living (dressing, washing, transferring independently, toileting, driving a car)[3,4] as for partecipating in sports and other recreational activities[5]. A regular program of exercises optimizes joint mobility and muscle activity in subjects with SCI[5] and can contribute to reduce the risk of upper extremities injuries, mainly overuse injuries of the RC[6,7], that range from 30 to 73%[8,9]. The main factor producing repetitive forces acting on the shoulder joint is the WC propulsion, especially the high peak force applied to the handrim that is mechanically straining[10,11]. In the health young population, subjects commonly affected by shoulder dysfunction are overhead sportsmen or workers, in which microtrauma (posterior capsular tighteness and internal impingement)[12,13] or a degenerative process (spur formation, RC thinning)[14,15] underlying the shoulder pathology. The aforementioned pathological conditions are not as well defined in patients with SCI, moreover there are no great literature evidence on muscular imbalance and strength in paraplegic[16,17], except for recent research articles describing the effects of resistance training on strength and pain in paraplegics[18,19] and isokinetic rotator cuff performance in WC athletes[20]. Isokinetic quantification muscular exercises has been described as a method

to understand muscular adaptations during athletic activities in WC users and WC athletes, detemining the influence of WC propulsion and neurological lesion level on peak torque, mean power and the internal/external muscle ratios[20].
Our hypothesis was that a training machine developed for able-body users was suitable for a population of paraplegic subjects who followed a standard protocol of shoulder exercises. In order to test this hypothesis the WC position for each exercise and their correlations with the variables examined in the study were recorded.

Material and methods

Study population

This was a prospective laboratory study performed between October and December 2012 on 11 subjects with paraplegia due to spinal cord injury who were asked to be enrolled in the current research project. The project was approved by institutional review board (protocol: 2735/2013) and overall patients gave their written informed consent to be included in this study that also included photographic and video documentation.
Demographic and anthropometric data of the study population are reported in the Table 1.
Overall patient were involved in sport activity as follow: hand-bike (6), WC basket-ball (3), fencing (2), rowing (1), mono-ski (1), tennis-table (1), golf (1) swimming (1).
The patients enrolled performed a mean of 6 weekly hours (SD:1.17) shoulder training.

Table 1. Demographic and anthropometric data of the study population.

Variable	Data	
Patients (N°)	11	
Mean age (years/SD)	38/8.34	
Gender (M/F) (%)	10/1	90.91/9.09
Mean height (cm/SD)	176/7.98	
Mean weight (kg/SD)	75/19.26	
BMI (mean/SD)	24/4.05	
Dominant side (right/left) (%)	11/0	100/0
CS (right mean/SD) (left mean/SD)	88/8.16	88/7.74
DASH (mean/SD)	6/5.35	
SCIM (mean/SD)	76/1.73	
Level of spinal cord injury (level) (N°)	T12, L3	1
	T12	2
	T10, T11	2
	T11, T12	1
	T12, L1	2
	T7, L1	1
	T4, T5	1
	L1	1

SD: Standard Deviation
BMI: Body Mass Index
CS: Constant-Murley Score
DASH: The Disabilities of the Arm, Shoulder and Hand
SCIM: Spinal Cord Independence Measure

Inclusion and exclusion criteria

Patients were considered eligible for functional shoulder evaluation if they were 18 years or older, had a clinical diagnosis of complete or incomplete dorsal or lumbar spinal cord injury detected with MRI, were habitual WC users and they practice sport activity, with no previous shoulder or upper limb injections within the last 3 months, availability for the duration of the study. Patients were excluded if they refused to consent to such a procedure, had a positive history of shoulder trauma, partial or complete RC tears, calcifying tendinitis, previous arthroscopic or open shoulder surgery, shoulder instability, infections or neoplasm, symptomatic cervical spine disease, rheumatoid arthritis or immune diseases, gout and uric acid diseases, severe medical conditions or were pregnant. Patients were also assessed for their mental status and excluded if they presented with cognitive limitations that could prevent them expressing a valid consent, or undergo subjective and objective evaluations.

Clinical evaluation

Neurological impairment
Neurological history showed that the vertebral level of spinal injury ranged from T4 to L3 (Tab. 1). The spinal injury level from T1 to T6 includes the full use of shoulders, arms and fingers movement with normal muscle strength, the trunk control is affected and there is a complete paralysis of lower body and legs. When the injury is located below T6 (T7-T12) the trunk control is preserved, while the upper limb, lower body and legs are involved as found for the level T1-T6. When the injury is at L1 we found a full use of upper body and paralysis of lower body and legs[21]. The rectus abdominis muscle and external abdominal oblique muscle control is generally preserved when the level of lesion range from T10-L1. In case of lesion at L2 or lower, the trunk control and abdominal muscle function are preserved but hip flexors and extensors, hip abductors and adductors, knee and ankle flexors and extensors may be impaired.
When the lesion is incomplete, the aforementioned motor function involvement is less clear and residual muscle activity below the level of spine injury could be preserved[22].
Among all patients recruited for this study 9 were considered functionally equivalent in terms of motion abilities and trunk control (injury level T10-L3), while 2 cases with upper spinal cord injuries (D4-D5, D7-L1) showed a more limited trunk control.
Clinical assessment of independence of each patient was performed using the Spinal Cord Independence Measure (SCIM III)[23] that consists of three complementary subscales: ‘Self care’ (with a score range of 0-20) including six tasks; ‘Respiration and sphincter management’ (with a score range of 0-40) including 4 tasks; and ‘Mobility’ (with a score range of 0-40) including nine tasks. The mobility subscale consists of

two subscales: one for 'room and toilet' and the one for 'indoors and outdoors, on even surface'. Total score ranges between 0 and 100.

Shoulder evaluation and outcome measures

A standard clinical examination was performed on each paraplegic subject who were included if we found the following clinical sights:

- pain-free arc of abduction and flexion
- no pain in the impingement position[24]
- no weakness of the rotator cuff[25]
- no pain or tenderness to palpation on the bicipital groove.

Overall shoulder function was assessed using the scale of Constant-Murley (CS)[26] and Disability of the Arm, Shoulder and Hand (DASH)[27].

The CS included a subjective questionnaire for pain, the ability to perform daily living activity (DLA), an objective evaluation of active range of motion (ROM) and strength. Pain was scored on a 15 point scale (0 severe pain, 15 no pain), while DLA was scored on a 20 points scale, with lower scores associated with greater impairment on DLA. ROM was measured using a standard goniometer between the upper arm and the upper part of the thorax. Shoulder strength was assessed using the Lafayette handheld dynamometer (Lafayette Instruments, Lafayette, Ind, USA), that has a microprocessor with a resolution of 0.4 lb (0.2 kg) in the range 0-50 pounds (0-22.6 kg), 0.03% accuracy with two calibration points: 0.25 and 50 lbs (0.11 and 22.6 kg). We assigned 1 point for each 0.5 kg of strength registered.

The Disabilities of the Arm, Shoulder and Hand (DASH) outcome measure is a self-report questionnaire scored in two components: the disability/symptom questions (30 items, scored 1-5) and the optional high performance sport/music or work section (4 items, scored 1-5). At least 27 of the 30 items must be completed for a score to be calculated. The assigned values for all completed responses are simply summed and averaged, producing a score out of five. This value is then transformed to a score out of 100 by subtracting one and multiplying by 25. This transformation is done to make the score easier to compare to other measures scaled on a 0-100 scale. A higher score indicates greater disability.

Equipment and instruments

The machine for shoulder training used for this research (Kinesis, Technogym SpA, Cesena, Italy) (Fig. 1A) was a rigid structure including 4 attachments, 2 inferior and 2 superior and a continuous cable loop system connected with double weight stacks (each stack weighs 79 Kg and is composed of 16 levels). Each cable manages one single weight stack and a pulley system which enable 3D movements (360°). The FullGravity™ technology of Kinesis allows for a vast range of movements involving all body areas. In order to perform the exercises correctly, the subject need to be placed 2 meters in front of the machine, with a stable ground surface.

Wheelchair features

Overall patients under the current research used a WC propulsion that could be moved manually pushing the wheels. WC had the following components[28]: back rest adjustable, rigid and padded suspension between the upright components of the seat frame used by the operator to rest his back. Wheelchair tires can be classified as pneumatic, semi-pneumatic or solid rubber. Manual brakes permit the wheels to be locked in place to prevent uncontrolled movements. Seat cushion made of soft tissues (as foam rubber, sponge) that are mechanically deformed by load bearing and permit wasting and adsorbing forces between the operator's body and the sitting surface.

Recording of wheelchair position

WC was placed lateral and frontal to the machine during exercise performance. A reference system has been defined to establish the position of the WC, using the wheel axis as a landmark for the position; specifically, the right wheel center was marked on the ground floor with adhesive tape for the exercises 1, 3, 4, 5, 8, 9 and for the exercises 2, 6, 7 performed on the left side of the machine (Fig. 1A-B). Conversely the left wheel center is marked on the ground floor with adhesive tape for the exercises 2, 6, 7 performed on the right side (Fig. 1A-B). Measuring tape was used to assess the position of each landmark.

Each landmark was defined by x and y coordinate and plotted in MATLAB software (MathWorks Inc, R2012a) using the "plot" command (Fig. 2). At the end of procedure data were reported on excel-sheet.

Exercises protocol

Since the machine under the current research was not a validated rehabilitation tool for paraplegic patients, before to start with the exercises protocol two raters (MG and DE) tested the reliability of the machine and the reproducibility of each exercises on 3 subjects with SCI at different time points using shoulder training protocol which will be described below. The reproducibility was found to be high for the exercises 1 to 5 and 9 (correlation coefficient = 0.80) and low for the exercises 6 and 7 (correlation coefficient = 0.60). We set a standard protocol of shoulder exercises following the principles reported by Kibler[29] and according to the manifacturer indications (Kinesis, Technogym SpA, Cesena, Italy).

Before starting the training all subjects performed a shoulder warm-up with cycle ergometer and elastic band for 20 minutes.

Exercise 1: Rowing (vertical handle)

The patients is placed in front of the machine, the

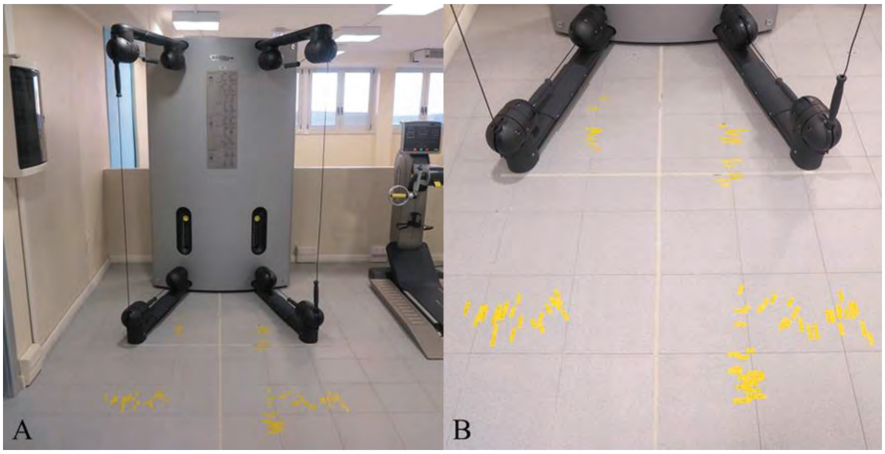

Figure 1 A-B. Training machine used in the current study (Kinesis, Technogym SpA, Cesena, Italy) (**A**). Ground landmarks with adesive tapes used to record the position of wheelchair's wheels (**B**).

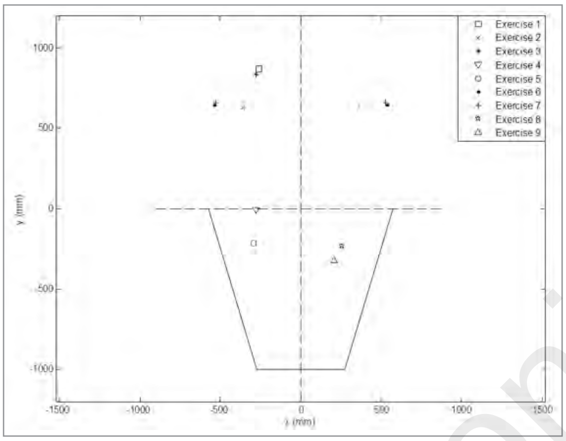

Figure 2. Graphic scheme descriving the position of the wheelchair for each exercise.

shoulder is flexed and abducted at 90° and the elbow extended (Fig. 3A). He makes a cable traction up, ending with the elbow flexed at 90° and the arm adducted to the trunk (Fig. 3B). During the traction he retracts the scapulae that is an essential part of the exercise.
Exercise 2: Horizontal pull-push (vertical handle)
The patient is placed to one side of the machine with the WC lateral and angulated of 60° respect to the machine (Fig. 4A). He alternates pushes and tractions with the right and left hands (Fig. 4B). This exercises is performed at both side of the machine.
Exercise 3: Pull-push trunk rotation (vertical handle)
The patient is placed in the same position of the exercise 1 (Fig. 5A). He makes a frontal adduction with one arm and a traction with the opposite arm (Fig. 5B) and vice versa.
Exercise 4: Reverse fly (low handle)
The patient is placed in front of the machine. He makes tractions of the cable starting with the shoulder adducted and the elbow extended (Fig. 6A) and ending with the shoulder abducted at 90° and elbow flexed at 90° (Fig. 6B). The scapulae are adducted and retracted.
Exercise 5: Lateral raise (low handle)
The patient is placed in front of the machine. He makes tractions of the cable starting with the shoulder adducted and the elbow extended (Fig. 7A) and ending with the shoulder abducted at 90° and elbow extended (Fig. 7B). The scapulae are adducted and retracted.
Exercise 6: Reverse wood chop (low handle)
The patient is placed to one side, lateral and parallel to the machine (Fig. 8A). He performs a trunk rotation and a cable traction upward (Fig. 8B). This exercises is performed at both side of the machine.
Exercise 7: Reverse wood chop (high handle)
The patient is placed to one side, lateral and parallel to the machine (Fig. 9A). He performs a trunk rotation and a cable traction downward (Fig. 9B). This exercises is performed at both side of the machine.
Exercise 8: Arm Adduction (high handle)
The patient is placed in front of the machine. He makes tractions of the cable starting with the shoulder abducted at 90° and elbow extended (Fig. 10A) and ending with the shoulder adducted and the elbow extended (Fig. 10B). The scapulae are adducted and retracted.
Exercise 9: Vertical pull-push (high handle)
The patient is placed in the same position of the exercise 8 (Fig. 11A). He alternates pushes and tractions with the right and left hands (Fig. 11B) and vice versa.

Statistical analysis

A descriptive analysis of the quantitative variables was conducted by calculating mean, standard deviation (SD), median and range as appropriate; absolute and percent frequency tables were calculated.
The Pearson's linear test and the Spearman's nonparametric test were used to see any correlation between the variables. The Stata Intercooled 9.2 software was used for all tests for Windows. The significance was set at $p<0.05$.

Results

All videos were analized to assess the technical per-

formance of each exercise and to register any case of muscle unbalance or loose of wheelchair stability.
All subjects but two were able to perform the exercises included in the training protocol. The cases n° 3 and 9 complained for pain and weakness of the lower trunk musculature and were unable to complete the exercises n° 6 and 7.
The average time required to complete overall protocol of exercises was 44 minutes (SD: 16.18).
No correlation was found between hours of weekly training and loading level used during each exercise. The values of the 2 variables (WC position and loading level) and related exercises are reported in the Table 2. The correlation was significant for the exer-

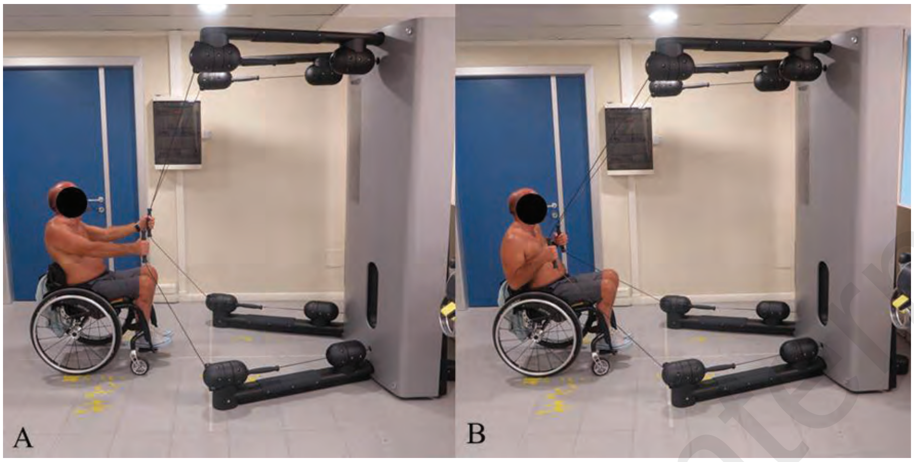

Figure 3 A-B. Exercise 1: start (**A**) and end (**B**).

Figure 4 A-B. Exercise 2: start (**A**) and end (**B**).

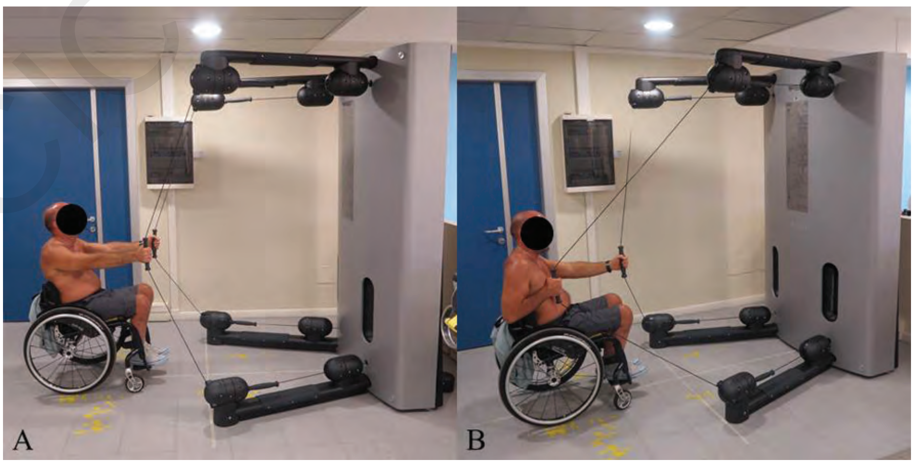

Figure 5 A-B. Exercise 3: start (**A**) and end (**B**).

cises n° 2 (p=0.0060) (Fig. 12), 3 (p =0.0074) (Fig. 13) and 5 (p=0.0003) (Fig. 14). Matching analysis for demographic and anthropometric data showed a significant correlation between body mass index (BMI) and loading level for the exercises n° 5 (p=0.0023) (Fig. 15) and 9 (p=0.0299) (Fig. 16) and between age and loading level for the exercise n° 7 (p=0.0088) (Fig. 17).

The location of SCI and loading level at each exercise are reported in the Table 3. The sample size was too small to perform an analysis of the statistical correlation between the level of SCI and loading at each exercise.

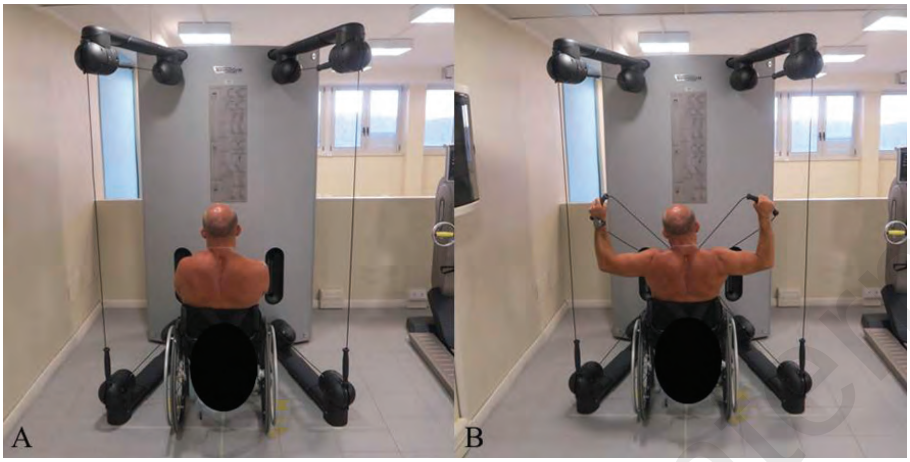

Figure 6 A-B. Exercise 4: start (**A**) and end (**B**).

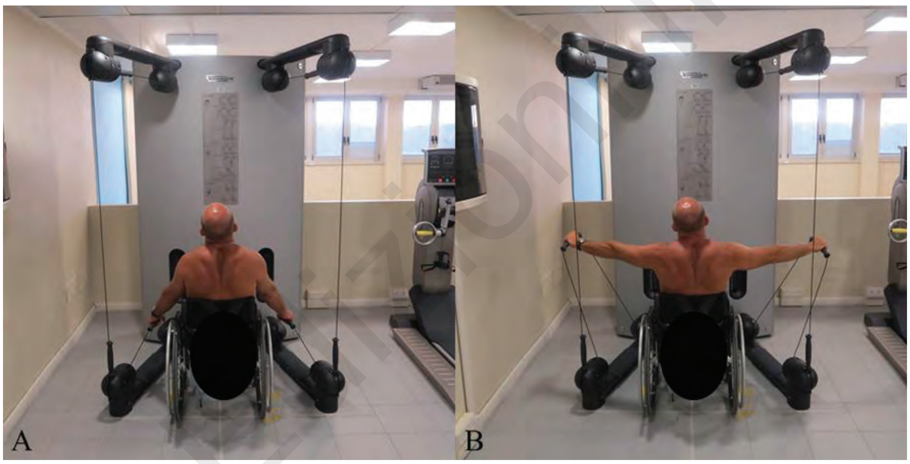

Figure 7 A-B. Exercise 5: start (**A**) and end (**B**).

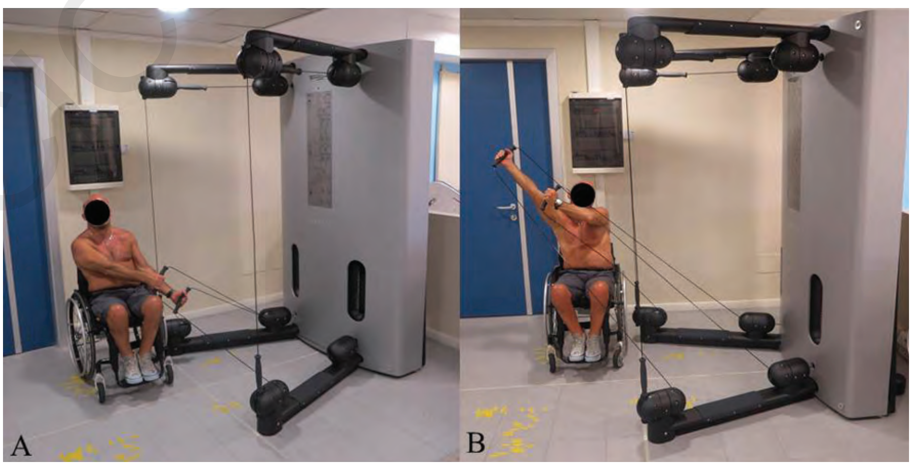

Figure 8 A-B. Exercise 6: start (**A**) and end (**B**).

The mean values of CS, DASH and SCIM are reported in Table 1. No correlation was found between clinical scores and loading level used during exercises as well as between clinical scores and anthropometric data.

Discussion

The primary findings of the current study was to provide useful informations to the many disabled subjects with SCI who carry out regular sport activities

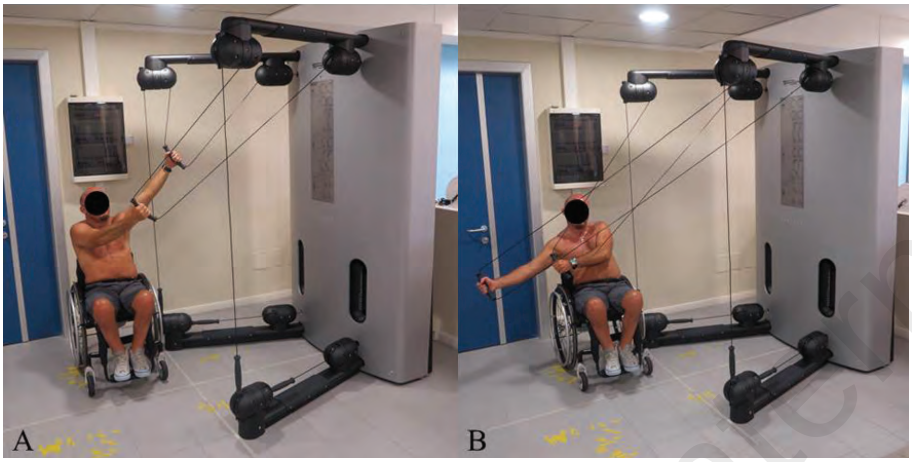

Figure 9 A-B. Exercise 7: start (**A**) and end (**B**).

Figure 10 A-B. Exercise 8: start (**A**) and end (**B**).

Figure 11 A-B. Exercise 9: start (**A**) and end (**B**).

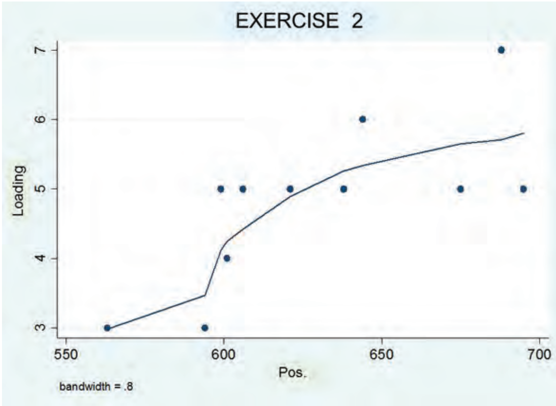

Figure 12. Correlation between position and loading level during the exercise 2.

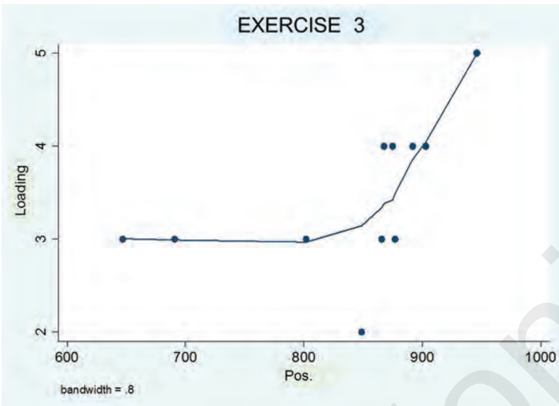

Figure 13. Correlation between position and loading level during the exercise 3.

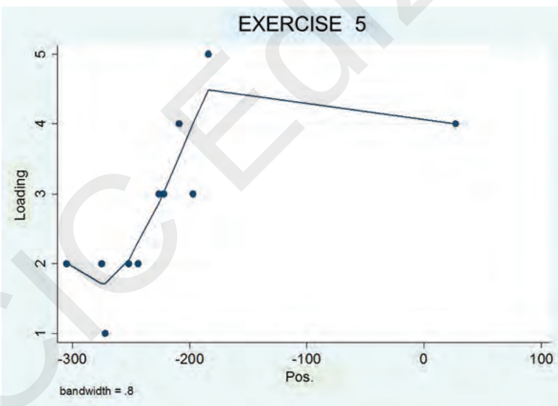

Figure 14. Correlation between position and loading level during the exercise 5.

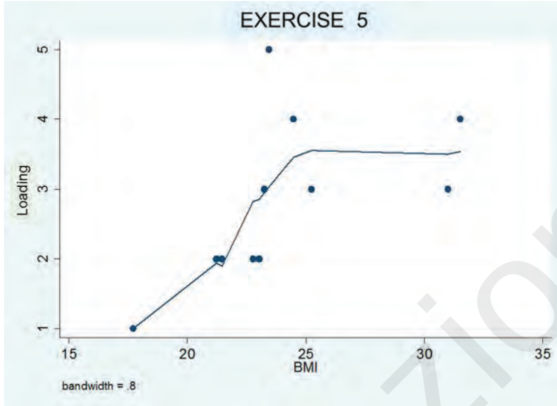

Figure 15. Correlation between body mass index and loading level during the exercise 5.

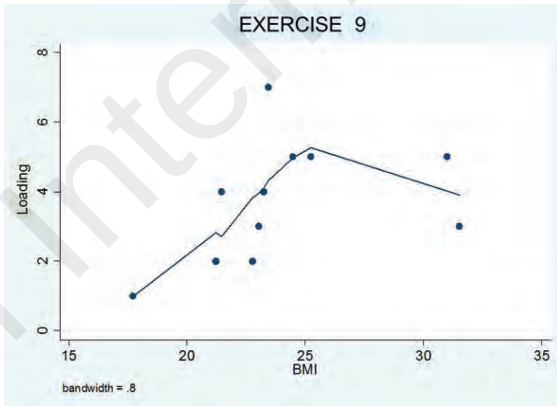

Figure 16. Correlation between body mass index and loading level during the exercise 9.

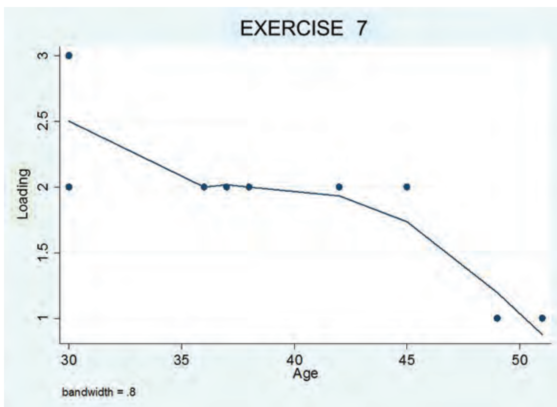

Figure 17. Correlation between age and loading level during the exercise 7.

with their upper limbs. The data collected are descriptive and analytics, regarding as the position of the WC as the capacity and appropriateness to perform the individual exercises. The training machine used in this research that was developed for able-bodied users, it has been tested in subjects with SCI without any manifacturer adjustements to see the way all the exercises were performed and to assess any abnor-

Table 2. Correlation between wheelchair position and loading level for each exercise.

Exercises	Position*	Loading Level	p value	r_s†
1	867 (64.99)	5.18	0.3648	0.3032
2	629 (42.56)	4.81	0.0060	0.7654
3	837 (91.04)	3.45	0.0074	0.7532
4	-7 (54.11)	1.45	0.2165	0.4051
5	-214 (87.86)	2.81	0.0003	0.8805
6	644 (38.13)	1.42	0.7023	-0.1782
7	657 (37.95)	1.88	0.7399	-0.1295
8	-235 (38.13)	3.63	0.9324	-0.0330
9	-325 (96.18)	3.72	0.5564	0.1995
		3	0.8920	-0.0465

* Data refer to mm (mean values) and standard deviation (SD)
† r_s: Spearman's rank correlation coefficient

Table 3. Mean loading values and vertebral level of SCI for each exercise.

		Exercise									
SCI location	**N°**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
		Loading									
T12-L3	1	5	5	4	1	3	1	2	5	3	5
T12	2	5.5	5	3.5	1.5	3.5	1/NA	2/NA	4.5	3.5	5
T10-T11	2	6	5.5	4.5	2	4	2	2.5	3.5	4	4
T11-T12	1	4	3	2	2	1	NA	1	2	1	1
T12-L1	2	5	5	3.5	1	2.5	1.5	1.5	5	2.5	3.5
T7-L1	1	3	4	3	1	2	NA	NA	3	1	2
T4-T5	1	5	5	3	1	2	NA	2	1	4	4
L1	1	7	5	3	2	3	1	2	3	4	4

SCI: Spinal Cord Injury
NA: Not assessed
Data refer to mean values

mal movements and muscle unbalance that represents a key point of the study.
On this regard, we found that most exercises were made with balance and appropriateness, even if the 7 subjects who were younger (mean age 34 years) and well-trained performed the training with more speed and alertness than the 4 older (mean age 47 years) and less trained subjects. Although the years of WC use may have affected the ability to perform physical exercises, a regular and professional program of sport activity, could have balanced the long-time of WC use, in fact, 2 out of 11 subjects who were professional athletes, had an optimal and balanced muscle mass of the upper trunk/shoulders and took less time to perform all the exercises (mean: 30 minutes) compared to the mean of the study population.
Nevertheless, overall found difficulties to perform appropriately the exercises n° 6 and 7, likely due to the weakness of lower trunk musculature. Specifically, 7 subjects with a SCI located from T10 to L3 performed the exercise n° 6 with a low loading level (mean value 1.4) and 4 were unable to perform the same exercise; of these last 4 patients, 1 had a SCI at T12, 1 at T11-T12, 1 at T7-L1 and 1 at T4-T5. Although the exercise n° 7 was quite difficult, 9 out of 11 subjects were able to perform it and all affirmed that the downward motion of the shoulder was easier and well tolerated; two subjects were completely unable to perform the exercises n° 6 and 7.
A stratified analysis have also showed a significant correlation between wheelchair position and loading level for exercise n° 2, 3 and 5. However, should be emphasized that a "confounding variable" due to individual anatomy (e.g. arm-lenght, seat-height) or wheelchair features (e.g. wheel diameter, back rest height, width and depth of the seat) may have affected the analysis of results[30,31].
BMI and loading level were significantly correlated with the exercises n° 5 and 9, finding the best correlation with BMI values of 25 that are consistent with research findings that set the value of BMI from 19 to 25 as an optimal weight[32,33].
An additional correlation was found between age and loading level for the exercise 7, that was optimal between 30 to 45 years.
The data arised from the current research do not support any consideration in order to the effects of completeness and incompleteness of SCI on the exercise performance and loading level; this represents a controversial and still inconclusive issue that needs to be deepened. As is common knowledge, wheelchair athletes are stronger around their shoulder than the

able-bodied athletes because their upper extremities can be considered their limb of propulsion and weightbearing. Several studies on baseball pitching[34], swimming[35] and waterpolo[36], showed difference in shoulder strength balance as compared to control, specifically, stronger shoulder internal rotators vs external rotators, and stronger adductors vs abductors were found[16]. Since the paraplegic athletes were spending about 90 hours per week in their wheelchair, the push phase of the propulsion concentrates on the rotator cuff the highest mean values of the muscle force shared as follow: supraspinatus (31%), infraspinatus (21%) and subscapularis (17%)[37]. In contrast, other athletic activities including circular movement and continous force application without propulsion (e.g. hand-cycling), entail lower glenohumeral contact forces, and rotator cuff muscles are not particularly stressed, producing a mean relative force of 6%[37]. Since a good balance of periscapular muscles is recommended to avoid upper limb injuries and pain[20], recent articles have reported the effects of shoulder resistance training programme on isokinetic and isometric strength, body composition, pain and functionality[19], showing that the treated patients had significantly increased shoulder strength in different scenarios immediately after the 8-week training period, founding an improvement in shoulder joint functionality, decreasing in pain perception and positive changes in body composition[19].

These results highlight the need for an appropriate shoulder training in paraplegic subjects, including eccentric and concentric exercises, similar to those performed in this study, therefore we do believe useful to report some informations on the current evidence on shoulder kinematics in wheelchair subjects. Manual wheelchair propulsion requires a pull-push action[38,39], starting with a flexion movement from a retroflected shoulder position, combined with a low-grade abduction that is converted to adduction during the last part of the push phase, where there is internal rotation to the ends of the movement[39]. The aforementioned movements include concentric and eccentric muscles contractions for the frequent changes between braking and propulsion, that affect shoulder muscular strength and fatigue[17]. Eccentric exercise is considered theoretically beneficial because it requires less muscular fatigue in spite of higher maximum strength and muscle tension[40-42]; additionally, overall metabolic and cardiovascular stress is lower in eccentric than in concentric forms of exercise[41]. These findings are supported by EMG measurements showing less activity under eccentric conditions in spite of higher strength development[40]. At the same time, structural musculature damage has been found as result of eccentric exercise, that can be considerably reduced with only a single repeat[43].

Mayer et al.[17] examined muscle fatigue, isokinetic peak torque and EMG activity eccentric (ecc) and concentric (conc) in 41 paraplegic subjects (13 early rehabilitants; 16 trained in wheelchair sports; 12 untrained) and they found that in eccentric exercise there was less muscle fatigue in all groups, highest ecc/conc peak torque ratio in trained subjects in all movements, followed by the untrained and early rehabilitants. The authors concluded that although the eccentric exercise requires lower muscle fatigue independent of the training status that induces structural damage and subjective pain, eccentric exercise is recommended with reservations in rehabilitation therapy and training[17]. These findings confirm that a program of shoulder training is applicable in preventing shoulder injury and promoting rehabilitation in the athletic and sedentary WC users. Our protocol included eccentric and concentric exercises performed without apparent difficulties by all the subjects enrolled except for 2 exercises, where the torso-rotation was limited due to the weakness of abdominal and lumbar musculature. Moreover, according to Mayer et al.[17] and Kuipers et al.[43], we adviced to perform a single eccentric exercise repeat in case of shoulder complaining during daily home training. There is a general consensus in the scientific literature, that a ripetitive motion and overuse is responsible for shoulder pathology among patient with SCI[1,2,7]. Besides, increasing frequency of damage to the shoulder is related to the overuse rather than to the age or time since the SCI[1,8]. The subjects enrolled in the study showed an optimal shoulder function and high clinical scores that were considered a precondition to be enrolled.

Finally, from the analysis of the data collected in this research we can state as follow: i) the training machine used in this research resulted to be a valid instrument for shoulder training in paraplegic but it needs some adjustments including a) a platform to secure the wheelchair, b) setting the height of each attachments, c) increase the distance between the inferior attachment for the best placement of the wheelchair, ii) the training protocol was overall appropriate except for the exercises needing a torso-rotation due to the weakness of the lower trunk musculature (e.g. abdominals and lumbars) and therefore we do believe that these kind of exercises should be taken off the protocol or performed applying an elastic band that limit the trunk heeling, iii) the accurate collection of the average distance between wheelchair and training machine represents a valid template for each paraplegic subject who decides to perform our training protocol, iv) the mean time recorded to complete the overall protocol of exercises should be reasonable for a well-trained paraplegic subject.

The study was challenging and involved seven authors, in particular 2 bioengineers have dedicated themselves to manual collection of data regarding the location of the wheelchair and the subsequent processing using MATLAB software and 2 experts in sport sciences took turns in teaching and follow the patients with exercises.

The limitation of the study includes i) the small sample size which does not allow drawing definite conclusions, ii) the training machine used in this research was developed for able-body users, without any adjustments for paraplegic subjects, iii) there is lack of a control group of healthy able-body users, iv) the variable distance wheelchair-training machine and the lack of a stable base of support could have affected the individual loading capacity.

Our considerations on the aforementioned limitations are in order: i) the sample size is small but adequate for a pilot study aiming to provide insights into a topic as controversial as shoulder training in paraplegic, ii) the training machine used in this research requires the adjustement reported above, iii) further investigations with a control group are needed, iv) the variability of the distance between wheelchair and machine is a limit that we think cannot be overcame while the need of a stable base of support has been reported in the suggestions above.

Despite such limitations[44] this pilot study provides fresh insight about the use of common machine for shoulder training, adapted for WC users. The protocol is susceptible of improvement and refinement but we think that our data offer new data to the current literature on wheelchair users training.

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