Use of vibration exercise in spinal cord injury patients who regularly practise sport

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Summary  

The aim of this study was to evaluate the applicability and effects of mechanical vibration on body composition and mechanical properties of the arm in patients with spinal cord injury (SCI). For this purpose, ten volunteers with thoracic SCI were recruited. Measurements were performed before and after a period of treatment with mechanical vibration applied during forearm flexion in isometric condition. The subjects were tested performing forearm flexion (both right and left side) with increasing loads, corresponding to 5, 8, 10 and 15% of their own body weight. Average velocity (AV), average force (AF) and average power (AP) were calculated. The Functional Independence Measure was used to evaluate daily autonomy at baseline. Total body and segmental (arms) body composition, fat mass, fat-free mass, and bone mineral density, were studied by dual energy X-ray absorptiometry. Functional measurements (AV, AF, AP) and body composition were measured at three time points: after a medical examination and interview (T0); after an interval of 12 weeks without physical therapy or training (T1); and finally after a further 12-week period during which the patients performed segmental vibration exercise (T2). The results showed statistically significant increases in AV and AP on the right (dominant) side (p<0.05); AF also increased, but without the difference reaching statistical significance. Total body composition did not change whereas the bone mineral density of the arms was higher after treatment, but again without the difference reaching statistical significance.  

KEY WORDS: rehabilitation, spinal cord injury, vibration.

Introduction  

Segmental vibration exercise (SVE), already used to stimulate the neuromuscular system in athletes (1) and for the prevention and treatment of osteoporosis (2), is a relatively new type of treatment. The technique is characterized by the continuous occurrence of alternating flexor-extensor contractions, as shown by amplitude increases in the electromyogram (3). Bosco et al. (4) reported that whole-body vibration enhanced explosive power performance in physically active subjects and increased testosterone and growth hormone levels (5). We set out to investigate the applicability of SVE in patients with spinal cord injury (SCI), studying the strength and body composition of these patients before and after a home SVE program. The variables considered in this protocol were average force (AF), average power (AP), average velocity (AV), fat-free mass (FFM), fat mass (FM), bone mineral density (BMD) and the Functional Independence Measure (FIM). In these investigations, a vibrating handlebar was used and the SVE was performed in a standardized position for both arms. The aim of the study was to evaluate, in patients with SCI, the effects of vibration on body composition and on mechanical properties of the arm.

Materials and methods  

Subjects  

The study was approved by the Ethics Committee of the University of Rome “Tor Vergata”. All the subjects gave their verbal and written informed consent before entering the study. The participants, after two were excluded for medical reasons and a further subject dropped out during the course of the study, were 10 paraplegic men, aged 34±4 years. All were examined by the same physician. All the patients presented a traumatic spinal cord lesion between the eighth and tenth dorsal vertebrae and had previously undergone spinal decompression surgery. The mean time since sustaining the SCI (in all cases in a car or motorcycle accident) was 8±3 years. All the patients had no lower limb sensory or motor function and used a manual wheelchair. Their mean FIM was 90±5. The subjects were all regular, recreational swimmers who did an hour of moderate swimming training three times a week. They had started this training programme, on average, three years before the start of our study. For the duration of the study they suspended this activity. No subject reported arm joint or muscle-tendon injury in the previous twelve months.
Body weight, height, body mass index

All the body composition assessments were carried out at the same time of the morning in all the subjects. Body weight and height were measured using a special balance with chair incorporated (Chinesport, Udine, Italy) and a height stadiometer (Invernizzi, Rome, Italy) to the nearest 1 kg and 0.5 cm, respectively. Patients were weighed first thing in the morning following overnight fast. Body mass index (BMI) was calculated using the standard formula: body weight (kg)/height (m²) (6).

Body composition

Regional and total soft tissue composition (lean and fat content), bone mineral content (BMC) (g), and bone mineral density (BMD) (g/cm²) were determined by dual energy X-ray absorptiometry (DXA). Measurements were performed with a total body scanner (Model DPX, Lunar, Madison, WI, software revision 3.6) that uses a constant potential X-ray source at 12.5 keV and a K-edge filter to achieve a congruent beam of stable dual-energy content (40 and 70 keV). The subject position and scan procedures were similar to those described by Mazess (7). Fat-free mass was calculated as the sum of BMC and lean body mass. The scanner was calibrated daily, again using the standard calibration block supplied by the manufacturer to control for possible baseline drift. Dual energy X-ray absorptiometry measures of total BMC, FFM and FM show a good level of accuracy, as described by Inukai et al. (8).

Experimental design

Ten minutes of standard warm up was performed, consisting of five minutes of free load exercise for hand, elbow and shoulder, followed by five minutes of static stretching exercise for the arm, upper arm and shoulder muscles on both the right and left sides. Following a four-minute rest at the end of the warm up the subjects performed four series of maximal speed arm curls, the load being increased with each series (handlebars plus an extra load corresponding to 5 and 8 and 10% of body weight. For each series, the best out of three measurements was recorded. The handlebars were linked mechanically to a linear encoder, interfaced with an electronic microprocessor (Muscle Lab, Ergopower; Ergotest Technology, Langen, Norway). The AV, acceleration, AF and AP for the various load displacements were calculated. The dynamic exercise reproducibility assessment gave a test-retest correlation of r=0.95 (9).

The FIM was administered before and at the end of vibration exercise treatment (10); before to establish the patient’s level of disability and at the end to look for correlations between functional scale and strength parameters.

Treatment procedures

The subjects were exposed to segmental vibration using vibrating handlebars (NEMES Bosco System, Rieti, Italy). For the purposes of this study, the frequency of the vibration was set at 30 Hz. The patients were exposed to the vibration daily for total of five minutes (five 60-second exposures, separated by 60-second rests). The treatment was repeated five times a week, for twelve weeks. After five consecutive days of treatment the patients had two days’ rest (Saturday and Sunday). The treatment, during which the patient was seated, was performed in exactly the same way on the right and left sides. The elbow angle was pre-set at 90° flexion, with the upper arm resting against the trunk and the shoulder in the neutral position. The trunk position (hip-trunk angle of 90°) was the same for all the subjects.

Statistical analysis

The statistical analysis was performed using SPSS 11 (Windows T version) software. All variables are described as mean values±SD. Percentage values arcsen (p/100)½ transformation was performed in order to adapt to normal distribution. Kolmogorov-Smirnov test was used to verify normal distribution and Levene’s test to verify variance homogeneity. When conditions of applicability were satisfied, the ANOVA test was used. The level of significance was set at p<0.05.

Results

Table I summarizes the patients’ baseline characteristics. No differences were found in mechanical behavior between T0, the first session before the start of the vibration exercise treatment, and T1, the second session, undertaken after the 12-week wash-out period. We used a wash-out period of 12 weeks to minimize the effect of any training or treatment of different kinds that the patients may previously have undertaken. For the entire duration of the protocol no subject undertook any other physical therapy, therapeutic exercise or sports training. Otherwise, their social life and lifestyle were unchanged. At T0, a statistically significant increase in the FFM was found between the dominant arm (right, in all the subjects) and the non-dominant arm; this difference between sides persisted after the vibration exercise (Table II). Following the program of vibration exercise (T2), the dominant arm showed statistically significant improvements in AP and AV when the test was performed with an extra load corresponding to 5 and 8 and 10% of body weight. When an extra load of 15% of body weight was

| Table I - The characteristics of the subjects at first examination (T0). |
|-----------------|-----------------|-----------------|-----------------|
| Age (years)     | 34.2±5.3        | BW (kg)         | 67.3±3.2        |
| FM (%bw)        | 24.0±3.13       | FIM             | 90.7±5          |

Abbreviations: BW=body weight; FM=fat mass; FIM=Functional Independence Measurement score.
used, the AP was still increased but the difference was not statistically significant. AF, after the vibration exercise protocol, increased (on the dominant side) with each extra load applied, but no statistical significance was found. (Table III). Total body DXA measurements showed no statistically significant differences between T0, T1 and T2. Segmental analysis showed an increase of arm BMC and FFM both on the right and the left side (Table II) but no statistical significance was found.

Discussion

Other authors have demonstrated the importance of home training programs for elderly patients to prevent osteoporosis and loss of muscle mass (11-13). Reductions in BMD and muscle mass are also characteristic of SCI patients. The present study was carried out to study the applicability and effects of SVE on upper arm training in SCI patients and to evaluate the validity of vibrating handlebars for home rehabilitation training of these patients, undertaken with the aim of increasing muscle strength and preventing osteoporosis. The literature contains contradictory results regarding the chronic effects of vibration. The physiological effects of vibration could be related to an increase in muscle activation caused by augmented excitatory input from muscle spindles exposed to vibration, or, thanks to better intramuscular coordination, to an increase in the ability to activate agonistic muscles optimally and to decrease excessive activation of antagonists (14).

Increased muscle strength in these patients can improve their autonomy in everyday activities and help to prevent joint impairment. Patients usually report limitations when trying to load their wheelchair into the car, in postural transfers (from wheelchair to bed, wheelchair to water and other), and when going up ramps in their manual wheelchair. These parameters cannot be evaluated by a functional scale and, in fact, no difference was found between the FIM at T0 and at T2. This unchanged FIM is in accordance with what is described in the literature (10), but all the subjects told us that their autonomy in postural transfers and wheelchair propulsion had increased. Our data suggest that SVE could represent an efficient method of home training for wheelchair users when the aim is to improve muscular efficiency, above all when the patient is young, or as preparation for a sports activity in which increased muscular efficiency can improve physical performance and protect against tendon and joint injury. Vibration may be a helpful technique in the home training of SCI patients.

Data from other authors suggest that wheelchair use

Table II - Segmental body composition parameters on the dominant (right) and non-dominant (left) side before and after treatment.

<table>
<thead>
<tr>
<th></th>
<th>Right side</th>
<th>Left side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before (T1)</td>
<td>After (T2)</td>
</tr>
<tr>
<td>AFM (g)</td>
<td>613±152</td>
<td>661±90</td>
</tr>
<tr>
<td>ABMC (g)</td>
<td>250±30</td>
<td>271±55</td>
</tr>
<tr>
<td>AFFM (g)</td>
<td>3759±340</td>
<td>3886±460*</td>
</tr>
</tbody>
</table>

Abbreviations: AFM=arm fat mass; ABMC=arm bone mineral content; AFFM=arm fat-free mass. Mean values±standard deviation; *Significant difference before and after treatment p<0.05.

Table III - Effect of vibration training on muscular performance.

<table>
<thead>
<tr>
<th>Load</th>
<th>Side</th>
<th>AP (W) Before</th>
<th>AP (W) After</th>
<th>AV (m/s) Before</th>
<th>AV (m/s) After</th>
<th>AF (Nm) Before</th>
<th>AF (Nm) After</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>D</td>
<td>51.7±8.0</td>
<td>60.2±11.7*</td>
<td>1.34±0.15</td>
<td>1.30±0.16*</td>
<td>38.9±5.8</td>
<td>45.8±11.6</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>74.4±8.6</td>
<td>59.9±14.0</td>
<td>1.26±0.12</td>
<td>1.43±0.14</td>
<td>37.0±5.7</td>
<td>40.7±8.2</td>
</tr>
<tr>
<td>8%</td>
<td>D</td>
<td>62.9±7.0</td>
<td>71.2±12.0*</td>
<td>1.16±0.17</td>
<td>1.22±0.13*</td>
<td>55.1±8.8</td>
<td>60.1±12.6</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>53.2±14.5</td>
<td>60.2±23.5</td>
<td>1.02±0.27</td>
<td>1.08±0.18</td>
<td>53.2±9.2</td>
<td>55.4±13.8</td>
</tr>
<tr>
<td>10%</td>
<td>D</td>
<td>59.2±11.2</td>
<td>73.2±10.1*</td>
<td>0.87±0.14</td>
<td>0.90±0.15*</td>
<td>68.9±7.3</td>
<td>82.6±19.0</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>59.9±15.5</td>
<td>70.9±20.0</td>
<td>0.89±0.22</td>
<td>0.91±0.16</td>
<td>69.1±7.3</td>
<td>71.0±12.6</td>
</tr>
<tr>
<td>15%</td>
<td>D</td>
<td>78.2±13.1</td>
<td>86.5±25.0</td>
<td>0.77±0.10</td>
<td>0.81±0.16</td>
<td>103.0±15.0</td>
<td>109.0±16.0</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>69.0±20.0</td>
<td>92.0±29.1</td>
<td>0.68±0.19</td>
<td>0.86±0.20</td>
<td>100.9±16.6</td>
<td>106.1±14.3</td>
</tr>
</tbody>
</table>

Abbreviations: D=dominant (right); ND=non-dominant (left); AP=average power; AV=average velocity; AF=average force. Measurements during arm curls performed with progressively increasing extra loads corresponding to 5, 8, 10 and 15% of body weight on right or left side. * Significant difference before versus after treatment: p<0.05.
may be associated with “vibration linked fatigue” (14) and that vibration may be a contributing factor to fatigue among manual wheelchair users. Fatigue can increase vulnerability to upper arm muscle and joint injury, whereas strengthening exercises can help to prevent injury (15). Vibration exercise, improving the performance and reducing the fatigue of the entire upper limb musculature, could help patients to avoid injury in everyday activities and sport.

Increased muscular efficiency can also help to increase autonomy, as in propulsive moment and postural transfers, and during sports activities. Other studies have demonstrated the effects of training on the biomechanics of wheelchair propulsion (15,16). Training can increase the loads these patients are able to manage in daily living, reduce accidents, increase maximum elbow extension angle, increase trunk and shoulder flexion-extension range of motion, increase hand rim propulsive moment, and increase power output. As expected, good training has a positive impact on the rehabilitation of the patient with SCI. Our data on vibration training in patients with SCI show an increase of AP and AV. It was surprising that different results emerged for the dominant and non-dominant sides. Differences in segmental body composition (Table II), in daily use, and in neuromuscular control strategies between the right and left arm could explain this finding.

Vibration exercise training does not exclude other types of physical treatment or training. Another study (2) investigating BMD and vibration used whole-body as opposed to segmental vibration and was longer than ours. Our data do not show same effect of vibration exercise on BMD. Further and longer studies of upper arm exercise vibration are needed, in particular to study hormonal response to segmental vibration treatment and the effects on whole-body BMD.

Our subjects showed good compliance with the segmental vibration treatment and, indeed, we had no reports of arm joint inflammation, muscle or tendon injuries. None of these wheelchairbound patients reported negative symptoms during, at the end of, or between the treatments, confirming the applicability of SVE in these patients.

Vibration exercise may be considered a good form of training to develop neuromuscular capacity, useful to improve manual wheelchair autonomy and for preventing shoulder and elbow injury in SCI patients.

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References