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Original Paper

Analysis of the Push-up Movement Based on Action Potentials of Upper Extremity Muscles and Ground Reaction Force between the Palms and a Force Plate

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Key words: push-up, spinal cord injury (SCI), ground reaction force

Abstract

In order to improve exercise therapy for patients with spinal cord injury (SCI), 13 healthy volunteers were asked to perform push-up movements of the trunk using the hands, and action potentials of upper extremity muscles and reaction forces between the palms and floor were measured. The same measurements were taken in 1 patient with SCI at the C6 level. The vertical component of ground reaction force and the action potential of each muscle were compared. Compared to the volunteers, the patient 's action potentials for shoulder girdle muscles were observed from the start of movement, and maximum potential was greater. Action potentials for shoulder girdle muscles were seen at almost the same time as those for elbow joint muscles, while action potentials for wrist muscles were seen later. SCI patients use different strategies compared to healthy individuals when engaging in push-up movements. Therefore, acquisition of an efficient push-up movement in SCI patients requires instruction in different movements to lift the trunk and improved mobility of the trunk and shoulder girdles and strengthening of shoulder girdle muscles.

Introduction

The push-up movement is important for paraplegic or quadriplegic patients with spinal cord injury (SCI). Without a wheelchair, these patients must move by lifting the trunk off the floor and moving the buttocks. As a result, the push-up movement is closely related to Activities of Daily Living (ADL) in paraplegic and quadriplegic patients.

Kikutani [1] investigated push-up height, upper arm muscle torque and leg and trunk flexibility in paraplegics and quadriplegics with SCI below C7. While not focusing on the push-up movement itself, Bergstrom [2] studied patients with SCI below C6 and examined whether these patients could move from a wheelchair to bed in terms of anthropometric measurements. Through these studies, some physical functions and anthropometric factors affecting push-up and transfer movements have been identified. Furthermore, the following factors reportedly influence the push-up movement: 1) extremity and trunk muscle strength and range of motion (ROM) ; 2) trunk balance during movements; and 3) timing of movement initiation [3-8] .

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In the present study, in order to improve exercise therapy for patients with SCI, 13 healthy volunteers were asked to perform push-up movements of the trunk using the hands, and action potentials of upper extremity muscles and ground forces between the palms and floor were measured. The same measurements were taken in 1 patient with SCI at the C6 level, and results were compared to typical results of volunteers.

Subjects and Methods

Subjects comprised 13 healthy men with a mean age, body weight and height of 23±2.9 years, 64±6.2 kg and 171±5.8 cm, respectively, and 1 37-year-old man with incomplete SCI of the 6th cervicale (C6).

This patient had injured his spinal cord 16 years ago, and according to Zancolli's classification, the manual muscle test (MMT) of residual muscle at C6B was at G level and was P to T level below C6B. Sensory disturbance below the C6 was classified as torpor, and deep tendon reflexes were elevated. The patient was able to change clothes, eat with self-help devices, get into a wheelchair from the anterior direction, and operate a wheelchair.

After sufficiently explaining the purpose of the present study, consent to undergo surface electromyography and a ground reaction force test was obtained.

Action potentials were measured and recorded using a multi-channel electromyograph (Multi Signal System ME3000P: Megaelectronics, Finland). Silver disc electrodes were placed on the following 12 areas: upper and lower sections of the right trapezius muscle; pectoralis major; latissimus dorsi; anterior and mid sections of the deltoideus; biceps brachii; triceps brachii; extensor carpi radialis brevis; extensor carpi ulnaris; flexor carpi radialis; and flexor carpi ulnaris (Fig. 1).

Ground reaction force was measured using a ground reaction force plate (92B1B/94211; Kistler, U.S.A). Each subject was instructed to place their palms on the plate and to push up their upper body to measure force components. Volunteers were instructed to push up the trunk using the hands and move the buttocks upward, forward and backward, but the SCI patient was only able to move his upper body upward, not forward or backward.

Action potentials were subjected to integration and recorded in synch with the ground reaction force test.

Fig. 1 Electromyography during push-up movement
Each action potential was measured and recorded using silver disc electrodes, although this does not show electrodes placed on a few muscles.

Results

1. Volunteers

Regarding time course for ground reaction force and action potentials for volunteers, Fig2 shows a typical time course for 13 volunteers. Maximum action potentials were seen with the forearm and upper arm muscles, muscles attached to the trunk and scapula (trapezius) and muscles attached to the trunk and humerus, in that order (Fig. 2). That of other volunteers tended to be alike. Upward movement primarily involved the deltoideus, pectoralis major and triceps brachii muscles. Forward movement mostly involved the latissimus dorsi, pectoralis major and triceps brachii muscles. Backward movement predominantly involved the deltoideus, pectoralis major, biceps brachii and triceps brachii muscles (Fig. 3, 4).

Ground reaction force was maximal with backward movement, followed by forward and upward movements, in that order, and reaction force for forward movement was in the negative direction (Fig. 5).

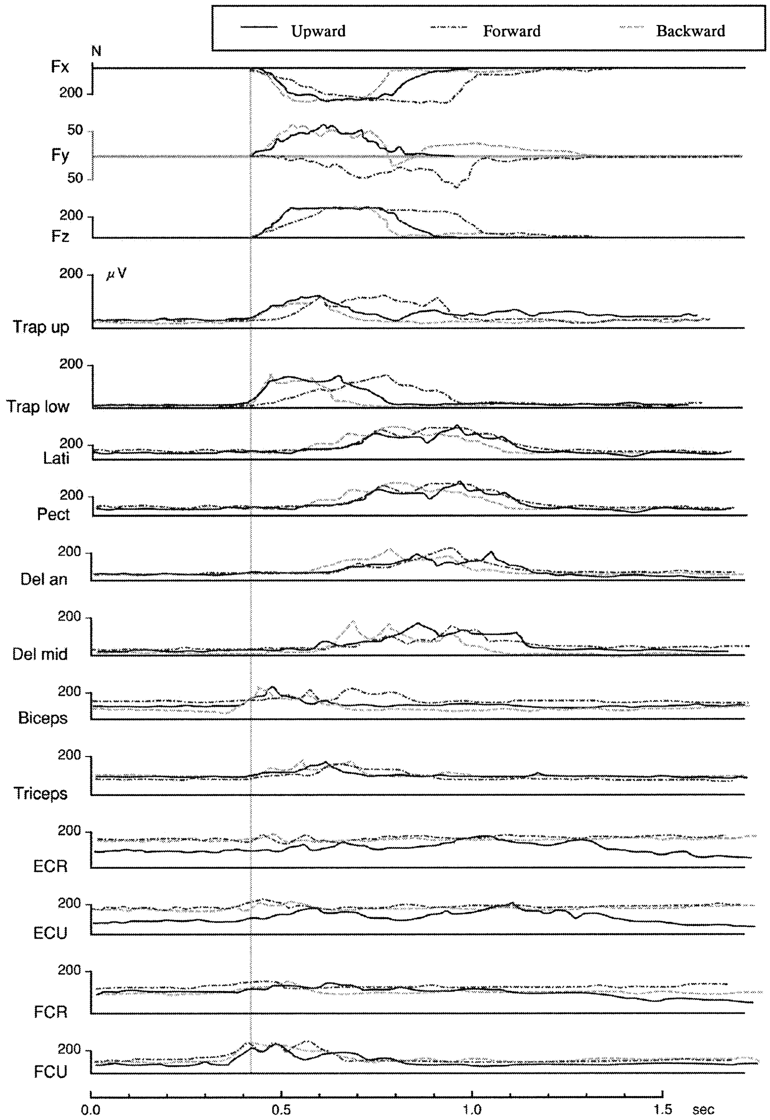

Fig. 2 Time course for ground reaction force and action potential during the push-up movement
This shows a typical time course for 13 volunteers. Maximum action potentials were seen with the forearm and upper arm muscles, muscles attached to the trunk and scapula (trapezius) and muscles attached to the trunk and humerus, in that order.

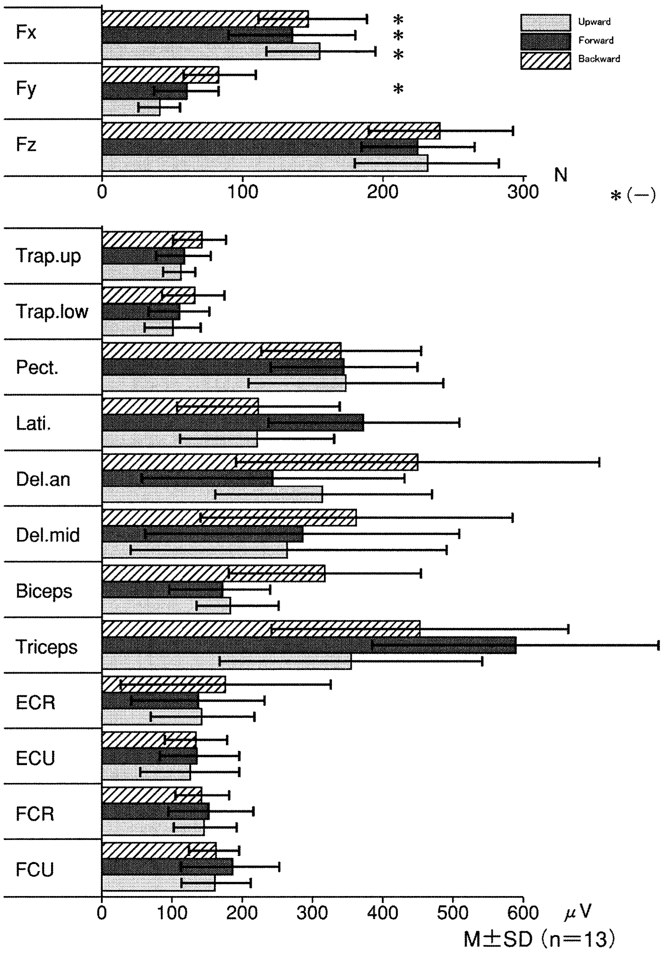

Fig.3 Action potential for upper extremity muscles during the push-up movement

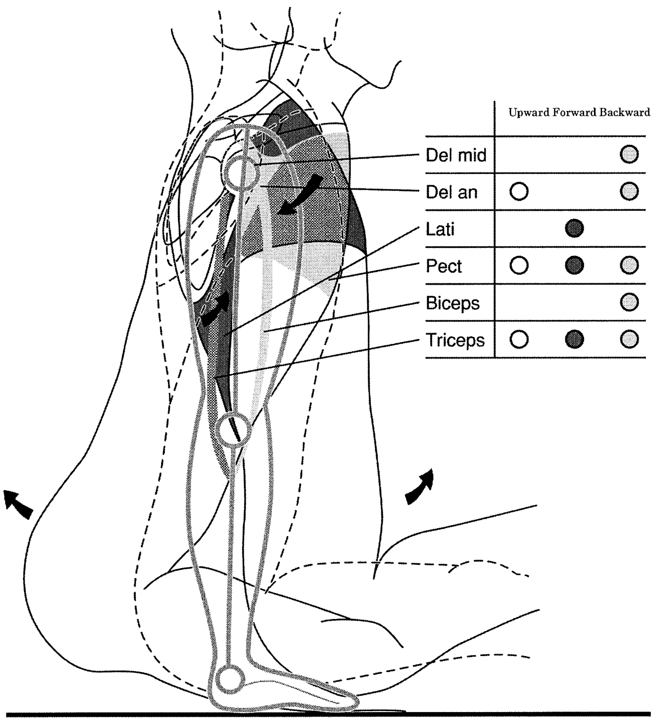

Fig.4 Muscle action with upper arm fixed to the floor

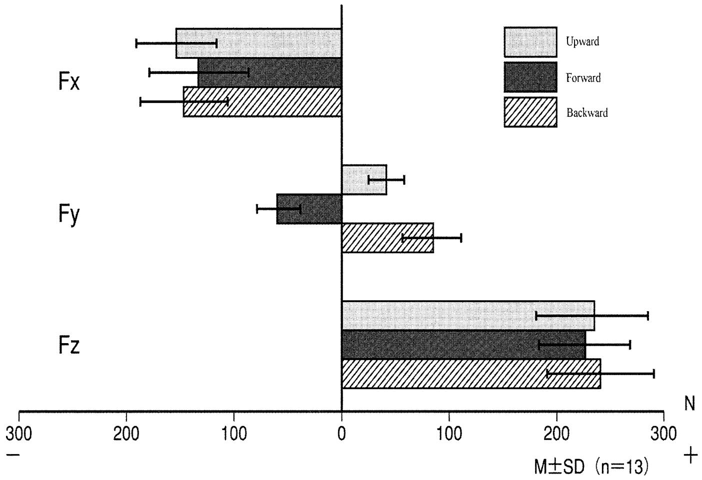

Fig. 5 Ground reaction force at the time of push-up movement

2. Comparison between the patient and a volunteer

Figure 6 shows the time course for ground reaction force and action potentials during the push-up movement for the SCI patient and one volunteer (a 22-year-old man). The vertical component of ground reaction force and the action potential of each muscle were compared, and the following 3 differences were noted:

1) Compared to the volunteer, action potentials for shoulder girdle muscles (trapezius, latissimus dorsi, pectoralis major and deltoideus) were observed from the start of movement. Action potentials for shoulder

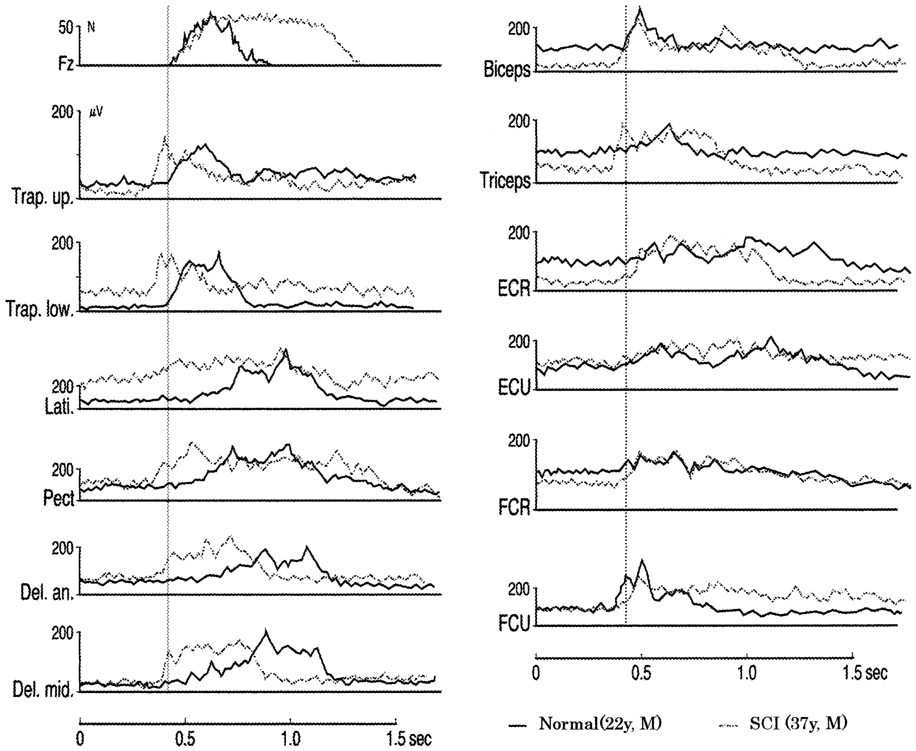

Fig. 6 Time course for ground reaction force and action potentials during the push-up movement
This shows the time course for ground reaction force and action potentials during the push-up movement for the SCI patient and one volunteer (a 22-year-old man).

girdle muscles (trapezius, latissimus dorsi, pectoralis major and deltoideus) tended to be large, although we could not compare the two because of the difference for skin impedance.
2) Action potentials for shoulder girdle muscles (trapezius, latissimus dorsi, pectoralis major, and anterior deltoideus) were seen at almost the same time as those for elbow joint muscles (biceps brachii and triceps brachii), while action potentials for wrist muscles were seen later.
3) While ground reaction force peaks were comparable, peak times were greater for the patient.

Discussion

For volunteers, muscular activities of the upper arm during the push-up movement could be divided into 2 chronological phases. In the first phase, muscles act to immobilize the upper extremity joints. In the second phase, muscles function to push up and move the trunk (Fig. 7). In other words, first-phase muscles immobilize the upper extremity joints, particularly the elbow, to fix the upper arm to the floor, forming a closed-link structure, including the contact between the foot and floor. The elbow is even more strongly immobilized by the biceps brachii to allow second-phase muscles to function more efficiently, and the trunk can be lifted and moved forward and backward smoothly.

Kikutani [1] and Mizukami [6] analyzed push-up movements for SCI patients, and reported the importance of mobility of the trunk and shoulder girdle and the muscles that rotate the scapula in the inferior direction. However, no comparisons to healthy individuals were made.

Based on the above findings, push-up movements in the SCI patient can be summarized as follows:
(1) Action potentials of shoulder girdle muscles (trapezius, latissimus dorsi, pectoralis major and deltoideus) are seen from the start of the push-up movement. As stated by Mizukami [6], these muscles are active instead of the trunk muscles to immobilize the trunk and shoulder girdle.
(2) Muscular activity for the push-up movement was biphasic, and while upper extremity muscles became active first, followed by shoulder girdle muscles in volunteers, this process was reversed in the SCI patient. This was because the SCI patient efficiently pushed up by immobilizing the trunk and shoulder girdle using

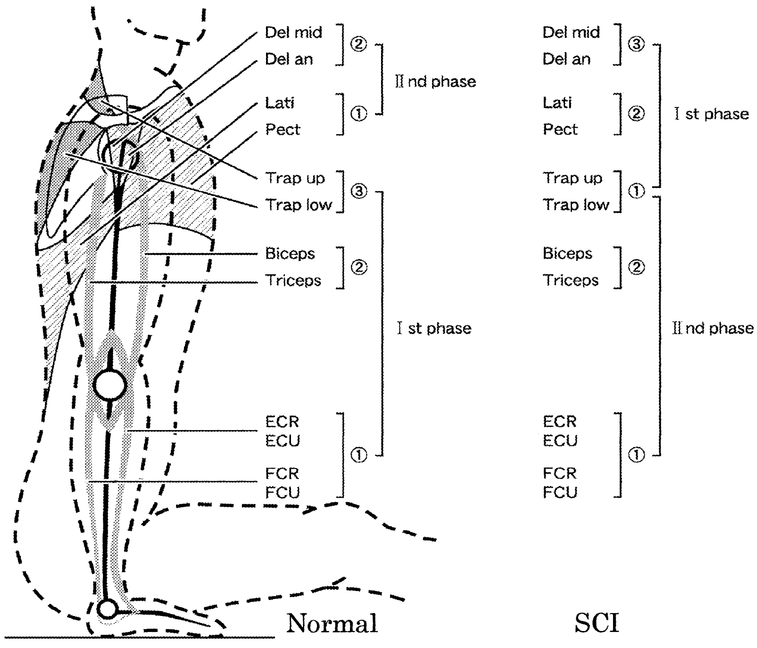

Fig. 7 Time course of contraction of shoulder girdle and upper extremity muscles during the push-up movement

the upper extremity and shoulder girdle muscles instead of trunk muscles.
(3) The cycle of ground reaction force was longer for the SCI patient, probably because the patient could not respond instantaneously due to paralysis of the trunk muscles.

Conclusion

These findings suggest that because the trunk muscles are paralyzed, patients with cervical SCI have to use the upper extremity and shoulder girdle muscles. In other words, SCI patients use different strategies to healthy individuals when engaging in push-up movements. Therefore, acquisition of an efficient push-up movement in SCI patients requires:
1) instruction in different movements to lift the trunk; and
2) improved mobility of the trunk and shoulder girdles and strengthening of shoulder girdle muscles.

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