Sitting Balance and Trunk Muscle Strength in Paraplegic Patients

KIYOMI TAKAYANAGI, RPT¹⁾, OSAMU YOSHIMURA, MD¹⁾, AKIKAZU NAKAYAMA, RPT²⁾,
FUMIO TSUTSUMI, RPT²⁾

¹⁾*Institute of Health Sciences, Hiroshima University School of Medicine: 1-1-89
Higashisenda-cho Naka-ku Hiroshima-city 730 Japan*

²⁾*Department of Physical Therapy, Kyushu College of Rehabilitation*

Abstract. Instrumentation surgery was applied to patients with spinal cord injury with the aim of correcting spinal deformity and assisting the patient in maintaining stability. In cases where long Harrington rods were used, however, trunk balance often became instable due to the loss of mobility of the spinal column. Using a weight balance analyzer, the sway of sitting balance was measured in L1 completely paraplegic patients fixed with Harrington rods and in those under conservative treatment. Abdominal and back muscle strength was measured using a Cybex II. In patients treated with Harrington rod, the sway of sitting balance was intense, especially during anterior movement. Dynamic sitting balance was inferior. Decreases in torque were not remarkable in isometric contraction of trunk muscles, while marked decreases were observed during isokinetic contraction. These results suggest that dynamic movement of the trunk muscles was restrained in cases fixed with Harrington rods due to stiffness of the spine, despite the fact that muscle strength was maintained.

Key words: Paraplegia, Sitting balance, Trunk muscle strength.

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INTRODUCTION

In much the same way as standing balance affect stroke patients, the ability of paraplegic patients to maintain sitting balance affects activities of daily living such as mobility, using the bathroom and getting dressed. Acquisition of sitting balance is thus the most basic concern in rehabilitation of spinal cord injuries. The sitting balance of patients with paraplegia is based on not only the stability of the spinal column and pelvis but also on various complex mechanisms including muscle strength, the senses, the position of the head and upper extremities and reflexes such as righting reflexes and equilibrium reactions. There is no single established method for the evaluation of these points, but they have generally been assessed with reference to the center of gravity, maximal tilting angle

of sitting surface, X-ray examination on the mobility of the spinal column, the reach of the upper extremities and changes in the method of body weight support. In stroke mandeville games, sitting balance is graded from normal to zero, as in the manual muscle test. In a 1983 wheelchair sports event, Strohkendol used a wheelchair from which armrests had been removed for the evaluation of sitting balance and presented the classification of ability with four grades (1-4).

There is controversy as to which treatment should be selected for early stages of spinal cord injury, conservative or operative¹⁻⁴⁾. Since no radical therapy exists for the treatment of injured spinal cords at the present time, the objective of treating early stages of spinal cord injury is to reconstruct a painless, resilient, supportive and movable spinal column and prevent a wide variety of complications including decubitus. Since the founding of

our hospital in 1949, we have experienced more than 1,000 cases of paraplegia. Initial treatment for dislocations and fractures involved in thoracolumbar injuries has changed with the passage of time. For example, we used to use invasive therapies such as plate fixing, but now conservative therapy using postural reduction by Guttman is our treatment of choice. But Harrington instrumentation and Luque segmental spinal instrumentation have been employed for thoracolumbar dislocations and fractures since 1979 and 1982, respectively^{5, 6}. In the practice of rehabilitation, however, there are a few problems with cases of spinal instrumentation. When compared with cases of conservative treatment, spinal instrumentation allows patients to receive rehabilitation in the training room earlier because of strong internal fixing but it renders stiffness in the spinal column conspicuous and acquisition of sitting balance poor during the clinical course which in turn impairs ADL. We measured sitting balance and trunk muscle strength (which is closely related to sitting balance) in patients on conservative therapy and on Harrington instrumentation in order to investigate the cause of poor sitting balance in the Harrington instrumentation cases.

SUBJECTS AND METHODS

All the subjects were male. Six were patients with T12, L1 complete paraplegia on conservative therapy who had completed rehabilitation. Six were patients treated with Harrington instrumentation (four to seven (mean 5.3) vertebrae fixed) and six were healthy adults who served as the controls. They were all in the same age group (Table 1). X-ray assessment of both conservative therapy and Harrington instrumentation cases revealed that all of them sustained unstable dislocations and fractures; however, there was no difference in the degree of instability.

First, we prepared a seat socket to support sitting balance using a weight balance analyzer designed for the evaluation of standing balance training to

measure dynamic sitting balance (Fig. 1). The measurement of sitting balance was performed on the patients with their arms folded (neutral position). The weight balance analyzer consisted of eight strain gauges and two force plates. An input signal transmitter in the control box randomly generated a target load which was LED-displayed on the indicator. The magnitude of the input signals was randomly set as the target load corresponding to 60–95% of the body weights of the patients; in the present study, the target value was 80% of the patient's body weight. Each force plate detected vertical repellent force from the floor; the differential between the front and back and between the right and left was displayed as an output signal on the indicator. The patients that participated in the test were asked to make an effort to allow the least possible deviation between the input given and their output while transferring stability back and forth and right and left as quickly as possible, and then maintaining the load without motion, and repeating this procedure, back and forth and then right and left, five times. The input signal was entered into a data recorder for data processing, while data from the weight balance analyzer was recorded with regard to nine parameters i.e., time required to stand, tilting-force, repellent force, the number of failures, trembling in the initial stage

Fig. 1. Weight Balance Analyzer

Table 1. Subjects (T₁₂, L₁ complete paraplegia)

	n	sex	age
conservative therapy cases	6	Male	21–41 (mean 33.5)
Harrington instrumentation cases	6	Male	24–38 (mean 32.0)
controls	6	Male	23–42 (mean 33.5)

Fig. 2. Parameters of Weight Balance Analyzer

(Error 1), trembling in the intermediate stage (Error 2), trembling in the late stage (Error 3), the time required to respond, and time to reverse response (Fig. 2). Of the nine parameters, the errors 1, 2 and 3 (which are closely related to dynamic sitting position), were compared with each other in terms of transfer back and forth and transfer from right to left.

Secondly, in order to examine the cause of poor sitting balance, we measured the trunk muscle strength using a Cybex II (Fig. 3). Each patient laid down on the Cybex table in a supine and prone position with both iliac crests and knees immobilized. The center of the arms were in a position correspond to the fifth lumbus. A five-second contraction and of the abdominal and back muscles was followed by a 10-second relaxation both of which were repeated ten times for the purpose of isometric and isokinetic exercise. The angular speed of the isokinetic exercise was 12 degrees/sec. (2 RPM), 30 degrees/sec. and 60 degrees/sec. The values were displayed as torque (feet-pounds) and work load, which were evaluated using the peak torque.

Fig. 3. Muscle strength measured by Cybex II

RESULTS

Sitting balance

Errors 1, 2 and 3, during the transfer from right to left, were $7.34 \pm 3.16\%$, $4.40 \pm 3.76\%$ and $3.21 \pm 4.50\%$, respectively, in cases of conservative therapy, and $8.26 \pm 3.25\%$, $5.96 \pm 4.04\%$ and 4.55

$\pm 4.62\%$, respectively, in cases of Harrington instrumentation. For transfer from right to left, there was no great difference between the conservative therapy cases and Harrington instrumentation cases. On the other hand, when shaking at forward transfer during the transfer back and forth was AD-converted, errors 1, 2 and 3 were $9.23 \pm 3.16\%$, 6.40 ± 3.94 and $3.76 \pm 2.85\%$, respectively, in con-

servative therapy cases, whereas in Harrington instrumentation cases, they were $12.21 \pm 4.21\%$, $9.79 \pm 5.26\%$ and $4.46 \pm 4.98\%$, respectively (Table 2). Consequently, the mean of these parameters was greater in Harrington instrumentation cases than in conservative therapy cases; instability between the transfer back and forth, especially at forward transfer, was significant (Fig. 4).

Table 2. Sway of right-left shift and back-forth shift (cm²)

		conservative therapy cases	Harrington instrumentation cases	
Error 1	right-left shift	7.34 ± 3.16	8.26 ± 3.25	$p < 0.005$
	back-forth shift	9.23 ± 3.16	12.21 ± 4.21	$p < 0.001$
Error 2	right-left shift	4.40 ± 3.74	5.96 ± 4.04	NS
	back-forth shift	6.40 ± 3.94	9.79 ± 5.26	$p < 0.001$
Error 3	right-left shift	3.21 ± 4.50	4.55 ± 4.62	NS
	back-forth shift	3.78 ± 2.85	4.46 ± 4.98	$p < 0.001$

Error 1: trembling in the initial stage.

Error 2: trembling in the intermediate stage.

Error 1: trembling in the last stage.

Conservative therapy case

Harrington instrumentation case

Fig. 4. Sway during anterior and posterior shift

Strength of the abdominal and back muscles

In the controls (healthy adults), the strength of the abdominal muscles was 86–111 (mean 94) foot-pounds (ftlbs) in isometric exercise and 76–108 (mean 92) ftlbs in isokinetic exercise at 12 degrees/sec. The strength of the back muscles was 93–120 (mean 104) ftlbs in isometric exercise and 91–118 (mean 101) ftlbs in isokinetic exercise. In the conservative therapy cases, the peak torque of the abdominal muscles was 53–105 (mean 71) ftlbs in isometric exercise and 40–81 (mean 61) ftlbs in isokinetic exercise, while the peak torque of the back muscles was 53–111 (mean 80) ftlbs in isometric exercise and 46–89 (mean 70) ftlbs in isokinetic exercise at 12 degrees/sec. In the Harrington instrumentation cases, the peak torque of the abdominal muscles was 30–91 (mean 70) ftlbs in isometric exercise and 17–60 (mean 30) ftlbs in isokinetic exercise, while the peak torque of the back muscles was 47–95 (mean 72) in isometric exercise and 15–61 (mean 31) ftlbs in isokinetic exercise at 12 degrees/sec (Fig. 5).

The above findings demonstrate that isometric and isokinetic contraction in the three groups studied (i.e., the controls, conservative therapy cases and Harrington instrumentation cases), showed higher peak torque in the back muscles than in the abdominal muscles. For isometric contraction, both the abdominal and back muscles showed high

torque, with the controls giving the highest torque, conservative therapy cases the next highest, and Harrington instrumentation cases the least. These differences, were not, however, great. On the other hand, in isokinetic contraction, torque in the Harrington instrumentation cases was significantly decreased; this was especially evident in the back muscle. When the angular speed was increased to 30 and 60 degrees/sec, the torque declined in both the controls and conservative therapy cases the patients treated with Harrington instrumentation however, were not able to reach these angular speeds and failed to generate any torque (Fig. 6).

DISCUSSION

From birth on humans are subjected to gravity; all kinds of activities and postures must be resistant to the force of gravity. Man can properly maintain his balance and posture and continue exercise because appropriate muscular tension continuously works by consolidating central nervous system information from proprioceptors such as the skin, muscles, bone, joints, internal ear and the eye. The human standing posture is basically unstable; however, antigravitational muscles that connect joints and hold the skeleton in an upright-position always generate constant tension so that stable posture will be maintained. Even if an external force is applied to the body, humans react in

Fig. 5. Peak torque of trunk muscles

Fig. 6. Peak torque during isokinetic exercise of back muscles

such a way as to maintaining balance. The ability of posture to adapt to various forces is referred to as "postural reflexes"²⁾.

In the case of paraplegic patients, postural reflexes such as the static postural reflex of localized equilibrium reaction and metameric equilibrium reaction are injured; because of this, righting reflex and equilibrium motor reaction at the upper levels will be utilized. At the same time, patients with spinal cord injuries have poor sitting balance as a result of the lack in peripheral sensory feedback, a decrease in pelvic stabilization capability, and a decrease in dynamic sitting surface due to atrophy of the buttocks, femoral muscles and soft tissues. For this reason, they usually employ enhanced thoracic kyphosis, decreased lumbar lordosis, pelvic posterior tilting and stabilization power within their range of movement. Dynamic sitting balance utilizes postural reflex caused by reflexing mobilities and non-paretic muscle function in the central nervous system.

In order to maintain sitting balance patients with upper thoracic injuries (thoracolumbar injuries) develop posterior tilting in the entire spine and posterior tilting, maintain the head and upper extremities in a forward position, and are supported by abdominal pressure, upper dorsal and anterior thoracic residual muscles. In patients with midthoracic injuries, the spinal column comes closer to the physiological curve because of the back muscles and part of the abdominal muscles. At the same time, trunk rotation is increased and sitting balance improved. In lower thoracic and lumbar injuries, pelvic posterior tilting is decreased, lumbar lordosis occurs, pelvic stabilization capability is increased, and gravity shifts forward;

as a result, sitting balance is improved.

Our measurement of variations in sitting balance using a weight balance analyzer demonstrated that dynamic sitting balance showed greater sway in anterior than in posterior tilting, and least of all in lateral tilting. In conservative therapy cases, great sway was observed in the same order as in Harrington instrumentation cases. Forward sway was especially great in Harrington instrumentation cases. The reason for a small sway in lateral tilting is that sitting during lateral sway is maintained by lateral rotation of the head/cervix and trunk, and by retraction and protraction of the shoulder girdle; non-paretic muscles in each of them. Anterior and posterior sway preserve the strength of the abdominal and back muscles; this muscular strength should perhaps be referred to as the presence of harmony in the nerves and muscle resulting from postural reflexes including quickness, controllability, accuracy and endurance, which leads to the quality of dynamic balance. For example, dynamic balance in actual ADL, such as raising the caster of a wheelchair, are maintained by the righting, and equilibrium and the abdominal and back muscles are infrequently used.

The strength of the abdominal and back muscles in Harrington instrumentation cases was then compared with that in conservative therapy cases; the peak torque in isometric exercise was lower in Harrington instrumentation cases than in conservative therapy cases. At the same time, the difference was greater in the abdominal muscle than in the back muscle, although there was no significant difference between Harrington instrumentation cases and conservative therapy cases. On the other hand, the peak torque in isokinetic exercise was lower in

Harrington instrumentation cases than in conservative therapy cases; even at a lower angle speed of 12 degrees/sec, the decrease was greater, and the patient was not able to match the increasing angular speed, that is, decreased mobility was evident as the angular speed was increased. It can therefore be concluded that the cause of poor dynamic sitting balance in Harrington instrumentation cases is a decrease in dynamic muscular strength rather than a decrease in muscular strength of the trunk; in other words, the trunk muscles are unable to work because of the stiffness of the spinal column, even though muscular strength can be maintained. The relationship between dynamic sitting balance and muscular strength is partly due to the coordination of nerves and muscles resulting from postural reflexes; however, it seems likely that the fact that anterior sway was greater than posterior sway in Harrington instrumentation cases is because of the more efficient function of the abdominal muscle together with abdominal pressure than that of the back muscle.

Harrington rods were removed from eight patients after placement in 1979. Dynamic balance and muscular strength were measured before and after removal of the Harrington rods in only three cases. At present, no uniform changes have been seen in terms of dynamic sitting balance and muscular strength after removal of the Harrington rods.

CONCLUSION

With the recent progress of spinal surgery, types of spinal instrumentation surgery including the Harrington method have been selected for the treatment of thoracolumbar injuries. It is true that the patients on spinal instrumentation are able to initiate rehabilitation procedure in the training room at earlier stages when compared to those treated with strong internal fixation. However, stiffness of

the spinal column becomes conspicuous during the course of prognosis, which impairs acquisition of ADL. In patients treated with Harrington instrumentation, sway is increased with the shifting center of gravity and sway during anterior shift is especially great and associated with poor dynamic sitting balance. One of the causes for poor dynamic balance in Harrington instrumentation is a decrease in torque at the time of isokinetic contraction of the abdominal and back muscles. It may be that although muscular strength is maintained, the trunk muscles are unable to move because of the stiffness of the spinal column, causing poor dynamic balance with deteriorating ADL and even lesser ability to perform in wheelchair sports.

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