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Case Report

Kinematic Analysis of the Locomotion of a Quadruple Amputee with Short Stumps

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ABSTRACT

Using a three-dimensional gait analysis system, we performed kinematic analysis of locomotion in a patient whose extremities had been amputated at high levels owing to Buerger disease. Results were compared with those of a healthy subject. During locomotion in the sitting position, the patient's body's center of gravity was extremely unstable. With regard to the lateral drop and rise, the thorax drops and the pelvis rises at approximately the same time. However, during rotation the thorax led the pelvis by a quarter phase. These trunk movements were different from those of a healthy bipedal subject. (Jikeikai Med J 2004 ; 51 : 129-34)

Key words : quadruple amputee, kinematic analysis, locomotion, thorax, pelvis

INTRODUCTION

In patients who undergo quadruple amputations at high levels, unaided locomotion is considered extremely difficult[1,2]. Even in patients with lower-extremity amputations at lower levels and intact upper extremities, locomotion and maintaining a sitting posture are difficult[3,4]. To our knowledge, no reports of the locomotor capacity of high-level quadruple amputees have been published. However, we hypothesized that a high-level amputee without extremities could perform locomotion in a sitting position, although the kinematics of movement would be markedly different from those of a healthy bipedal person.

In this study, we performed kinematic analysis of the locomotor skills of a healthy bipedal person and of a high-level quadruple amputee, who could perform locomotion in a sitting position.

CASE REPORT

One subject of this study was a 49-year-old man with a history of Buerger disease that developed at 19 years of age. In 1970, the left fifth toe was amputated. In 1971, the left foot and the right forearm were amputated. In 1976, the left knee joint was disarticulated. In 1979, the right hip was disarticulated and the left forearm was amputated. In 1983, the right shoulder joint and the left hip were disarticulated. In 1985, the left shoulder was disarticulated. Since 1985, the patient's physical condition has been

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stable and the patient has lived at home. In September of 1999, the patient was admitted to the Rehabilitation Support Institution of the Kanagawa Rehabilitation Center in an attempt to reduce the burden of nursing care and to increase activities of daily living (ADLs), because the patient's primary caregiver, his mother, was already of an advanced age. The patient was able to move about the rehabilitation center by pressing the joystick of an electrically powered wheel chair with his left shoulder. Although the patient could accomplish some ADLs by using a mouth stick, they were excluded from this report.

At the time of study there were no impairments in cognitive abilities and rapport was fair. Following the methods described in TC168 of the International Organization for Standardization[5–7], functional stump length was measured with radiography. An exception was the upper limb stump length: because the upper limb had been disarticulated at the shoulder joint, the stump length of the upper limb was measured from the acromion process of the scapula rather than from the axilla. Consequently, the distance between the shoulder and the acromion process was 6.0 cm on the right side and 8.0 cm on the left side. Both lower limbs had been disarticulated at the hip joint. The distance from the ischium to the thigh was 0 cm on the right side and 2.0 cm on the left side (Fig. 1).

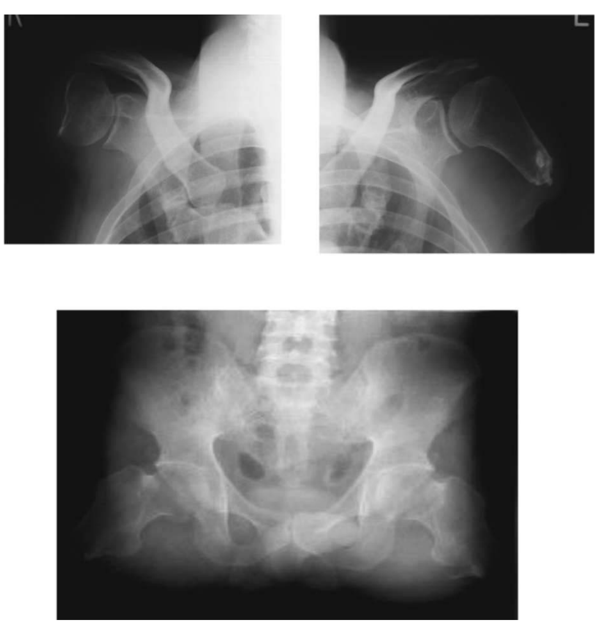

Fig. 1. X-ray film of 4 limb stumps.

The ranges of free automatic movement of the stumps of the lower extremities were as follows:

Right hip joint: extension, −20°; flexion, 90°; adduction, −40°; abduction, 70°.

Left hip joint: extension, −20°; flexion, 130°; adduction, −45°; abduction, 70°.

Both hip joints showed contractures in the flexion-abduction position. The range of movement of the trunk was 45° for extension and 25° for flexion. Although exact measurement of muscle strength at the stumps was difficult, neither obvious motor paralysis nor sensory impairment was evident.

Locomotion within the room consisted mainly of turning over, but crawling on the back was also possible. A change in the active self-supporting posture from lying to sitting was impossible, but once a sitting position was obtained with help, it could be maintained. Furthermore, locomotion in the sitting position was possible by alternately proceeding the right and left lower extremity stump/pelvis. In the present study, we observed how the patient moved his trunk during this movement in a sitting position. The results were then compared with the gait of a healthy bipedal subject, a 26-year-old man.

Methods of Kinetic Analysis

Before participating in the study, both subjects received an explanation of its aims and gave informed consent. The following analysis was then performed. First, to observe postural stability in the sitting position, we requested that the subjects move the trunk in the following directions while in a sitting position: anterior flexion, posterior flexion, right tilt, and left tilt. We measured the distribution of pressure exerted during these movements on the thigh stump and on the ground in contact with the pelvis by means of a gait scan (Nitta Co.) and an instrument for measuring sitting pressure.

Next, a total of 17 reflex markers were placed on various parts of the body, namely, 4 points on the head including the temple, 1 point on the bilateral acromion process, on the upper part of the body of the sternum, on the 7th cervical vertebra, the 10th thoracic vertebra, bilaterally on the anterior upper spines of the ileum, bilaterally on the upper posterior spines of the ileum, bilaterally on the lateral aspect of the thigh stumps, and a dummy point.

To measure gait, the subjects were asked to proceed with locomotor movement in a sitting position along a specific path in which 6 Anima force plates (80 cm×60 cm) were installed. We closely supervised the patient to prevent him sudden falls. Locomotion in the sitting position was monitored with 4 video cameras, and transitions of reflex markers on coordinates were analyzed by means of a three-dimensional gait analysis system (VICON 370).

Data were compared to the gait analysis of movements of the thorax and pelvis during locomotion in the sitting position in the healthy bipedal subject.

The height of the center of gravity was measured by measuring the position of the floor's antiforce action while the subject was supine. The position of the body's center of gravity was then calculated from these data using a computer[8].

Results of Kinematic Analysis

1. Dislocation of the body's center of gravity and contact between the bottom surface and the ground during rest while sitting upright

The dislocation of the body's center of gravity during 10 seconds of sitting upright while at rest was within 3 mm forward, backward and bilateral movements. Pressure distribution was concentrated on the ischial tuberosity on both sides, but the sitting position was judged to be supported by both the ischium and the bottom surface of the thigh on both sides. Forty-five degrees anterolaterally from each ischial tuberostiy the stump of the femur was in contact between the bottom surface and the ground. The body's center of gravity was, 41.7% of the body height measured from the bottom when the supporting surface was used as the reference. When only the trunk was considered, the center of gravity was 45.8% from the bottom.

2. During anterior flexion and posterior flexion of the trunk

When the patient was asked to perform anterior or posterior flexion of the trunk, the head and thorax moved forward or backward without any associated movement of the pelvis. When the body's center of gravity was dislocated forward, the load on the ischium was reduced and the load on the stump increased. However, the 25-mm anterior dislocation of the body's center of gravity was not sufficient. The patient fell down when he attempted to move more than this distance.

3. Lateral tilt of the trunk to the left-right direction

When we requested the patient to make a lateral tilting movement to the left or to the right, the movement started at the thorax, and during the last half of the movement cycle, tilting of the pelvis became greater than that of the trunk. The dislocation distance of the body's center of gravity was about 160 mm. In the anterior-posterior flexion the patient was unable to maintain balance despite a large dislocation of the body's center of gravity and an increase in the load on the stump.

4. Dislocation in the sitting position

Based on results of the 3-dimensional kinematic analysis of dislocation in the sitting position, we described movements of the thorax and pelvis during the period in which the right side proceeds using the left side as a support (during the period from the left side contact to the right side contact ; Fig. 2). Movements occurred in the following order : 1) rotation of the thorax to the left, 2) near simultaneous lateral drop of the thorax and lateral rise of the pelvis to the left, and 3) rotation of the pelvis to the left a quarter phase later. With regard to the lateral drop and rise, the thorax and the pelvis moved together with almost the same timing, but in rotation, the movement of the thorax led the movement of the pelvis movement by a quarter phase.

Dislocation distance of the body's center of gravity in the left-right direction was about 150 mm during

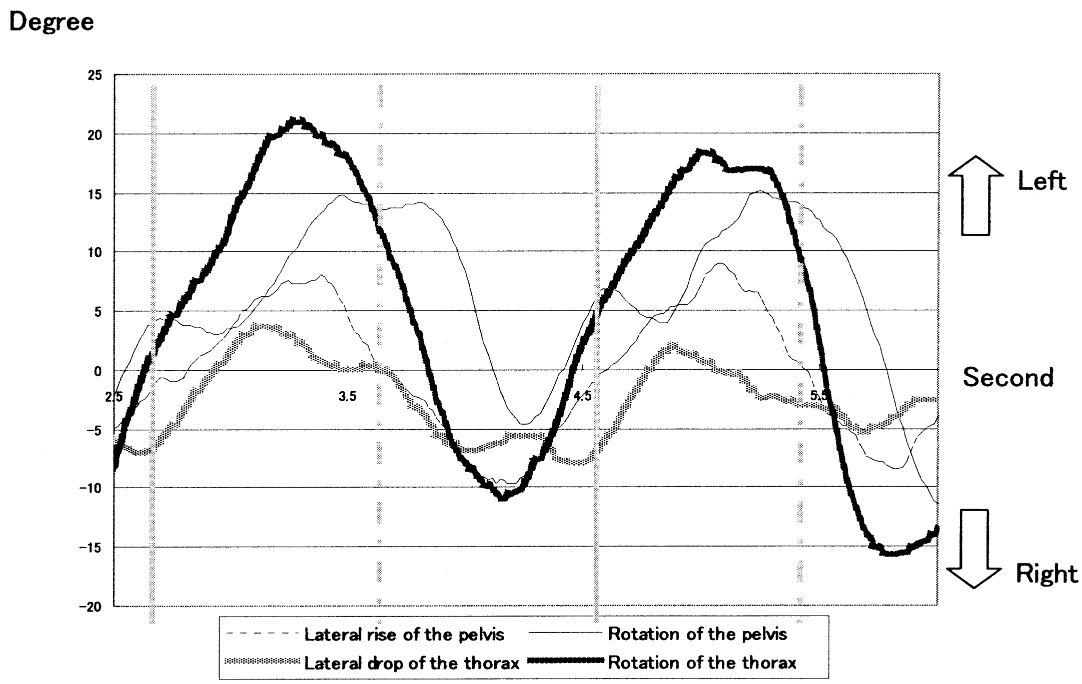

Fig. 2. Movements of the thorax and pelvis during locomotion with the patient in the sitting position. Following a lateral drop of the thorax, rotation of the thorax and elevation of the pelvis occurred almost simultaneously. As if following the preceding thorax, the pelvis rotated in the same direction.

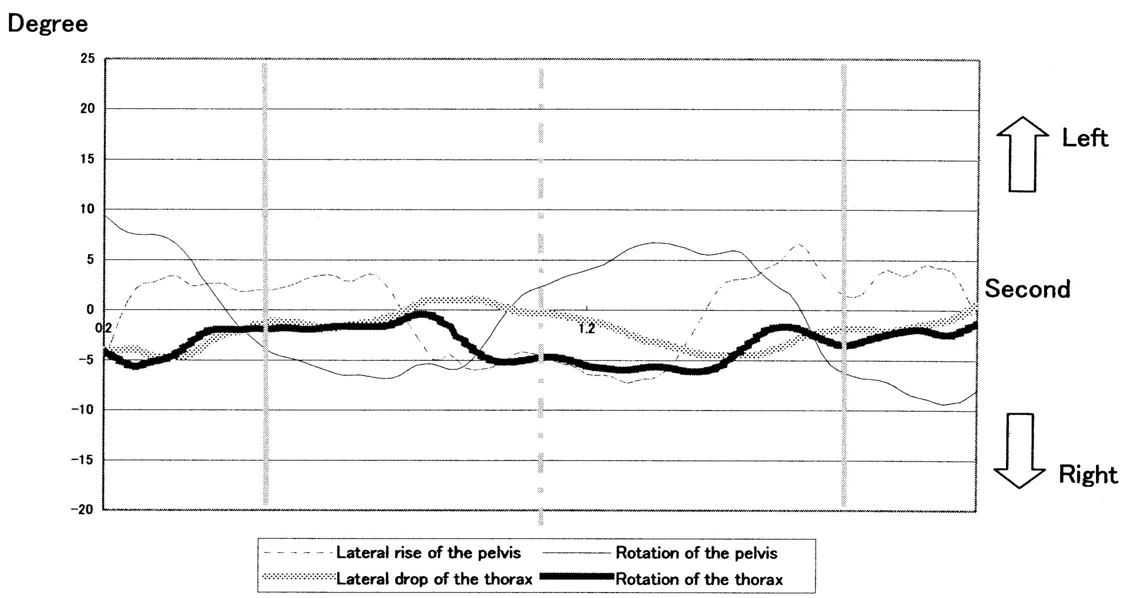

Fig. 3. Movements of the thorax and pelvis during bipedal gait of a healthy subject. In association with lower limb elevation, the pelvis rises laterally, and, a quarter phase later, the thorax rotates in the direction opposite to the pelvic rotation.

dislocation in the sitting position. For forward dislocation, 1 step was about 80 mm, but the rhythm and distance were varied and unstable. For example, the gain in distance with a step was sometimes null with the right side, but sometimes there was no gain with the left side. On the whole, the direction of movement was barely maintained.

5. Bipedal gait of a healthy subject

When the right side was advanced with the left side serving as a support, movements of the thorax and pelvis during bipedal gait in a healthy subject proceeded in the following order (during the period from the left contact to the right contact; Fig. 3): 1) lateral rise of the pelvis to the right, 2) about a quarter phase later, left rotation of the pelvis, and 3) almost simultaneously with pelvic rotation to the left, rotation and lateral drop of the thorax to the right. Therefore, the direction of thoracic rotation was opposite to the direction of pelvic rotation. The pelvis started the lateral rise, and the rotation and lateral drop of the thorax followed a quarter phase later.

Discussion

During upright rest in the sitting position, variation in the center of gravity of the patient's body was small and stability was high. The body weight was largely bilaterally supported by the ischium. Adjustment of the body's center of gravity to accommodate the supporting base and to obtain stability was not apparent from the external appearance but might be achieved by load adjustment of the under surface of the thigh and by slight head movements.

The vertical position of the body's center of gravity in healthy adults is at 55% to 56% of the body height with the sole as a reference[9,10]. Our patient had lost both lower extremities. Therefore, the body's center of gravity became lower and was 41.7% from the bottom. However, the center of gravity of the trunk was 45.8% from the bottom and did not differ greatly from the average of 48% in healthy adults[8].

Dislocation of the center of gravity of the patient's body by anterior-posterior flexion in the upright rest sitting position was 25 mm. This dislocation was extremely small compared with the 160 mm of lateral tilt. The reason the anterior-posterior movement was less stable than the lateral tilt are as follows: 1) because the femur was extremely short, the hip joint flexion moment could not be increased; and 2) in the supporting base plane, the anterior-posterior diameter was shorter than the lateral diameter.

In the sitting position, the direction of movement of the thorax and pelvis in our patient was extremely different from that in the healthy subject. In bipedal gait of the healthy subject, the thorax and the pelvis rotated in opposite directions[11,12]. In a patient with bilateral knee disarticulation amputation who used short nonarticulated prosthetic limbs, to compensate for the loss of knee and ankle articulations, exaggerated pelvic obliquity (hip hiking), transverse pelvic rotation, and hip abduction were needed to ensure limb clearance and a functional step length[13]. In contrast, in our patient the thorax and the pelvis rotated in the same direction during sitting locomotion. However, the rotation of the thorax occurred before the rotation of the pelvis; i.e., the thorax led the pelvis.

For example, when the patient's left side was the supporting side and the right stump proceeded forward, the thorax dropped to the left, followed soon after by the pelvis rising and the thorax rotating to the left. When the body weight was shifted to the left stump, and the right stump had cleared the floor sufficiently, the pelvis rotated to the left as if pulled by the thorax; as a result, the right stump could move forward. Left-right dislocation of the body's center of gravity during locomotion in the sitting position was 150 mm in this patient. This dislocation was much larger than the 58±20 mm in the bipedal gait of a healthy subject[8].

As mentioned previously, our patient could stably perform left-right dislocation of the body's center of gravity and, taking advantage of this ability, could laterally tilt the trunk until the contralateral stump was elevated. To make this movement possible, the stump of the femur, although extremely short, played an important role in maintaining balance. During forward dislocation of the stump, disorders in the left-right rhythm and distance were noted. This disorder was due to pain in the right ischial tuberosity which prevented loading of the right. After we learned about the pain in the right ischial tuberosity from this analysis, we placed a gel form cushion on the right side to encourage healing. Accordingly, in high-level amputees, when the stump cannot be loaded, when lateral dislocation of the body's center of gravity is sufficient to elevate one stump, or when rotation of the trunk is restrained, performing the locomotion observed in our patient might not be possible.

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