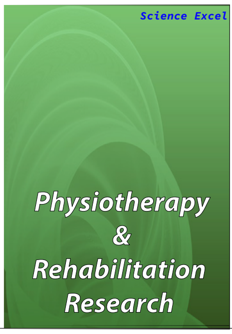
Physiotherapy and Rehabilitation Research

Case Series



Biomechanical analysis of quadruped movement in patients with spinal cord injury: A case series

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Abstract

Background: In the rehabilitation for patients with spinal cord injury, we often use developmental movement patterns of infants and Activity-Based Therapy. They include quadruped movement, but no reports of movement analysis on quadruped movement in patients with spinal cord injury.
Objective: This study aimed to analyze quadruped movement in patients with paraplegia, and to summarize its characteristics.
Methods: The quadruped movement of 3 patients with complete paraplegia were measured using a three-dimensional motion analyzer, and their characteristics were summarized.
Results: All cases showed an ipsilateral rotation of the pelvis when moving the lower limbs. Case A rose the contralateral upper and lower limbs simultaneously. Cases B and C moved one limb at a time.
Conclusions: Our results suggested that patients with spinal cord injury have an ipsilateral rotation of the pelvis when moving the lower limbs in quadruped movement. Also, it seems that, depending on the degree of disability, some cases were able to move the contralateral upper and lower limbs simultaneously, while others moved one limb at a time.

Introduction

The International Standard of Neurological Classification for Spinal Cord Injury (ISNCSCI), developed by the American Spinal Injury Association (ASIA) and the International Spinal Cord Society, is widely used for functional assessment of spinal cord injury. ISNCSCI determines the severity of paralysis (ASIA Impairment Scale: AIS) and Neurological Level of Injury (NLI) [1]. The motor function of the upper and lower limb described by the total score of each key muscles. Key muscle tests are limited to the 5th cervical spinal cord to the 1st thoracic spinal cord and the 2nd lumbar spinal cord to the 1st sacral spinal cord. Therefore, the motor function of the trunk is not included in the ISNCSCI. On the other hand, the importance of trunk function has been reported. It is confirmed that there are various types of trunk muscle coordination in patients with paraplegia, independent of AIS and NLI [2]. And the relationship between trunk function and ADL in patients with spinal cord injury has also been reported [3].

The interventions aimed at improving trunk function in patients with spinal cord injury are often performed. One of them is the quadruped movement. It is considered that there are similarities between quadruped movement in humans and quadrupeds [4,5], and it has been included in various rehabilitation concepts [4,6-8]. However, quadruped movement has been reported in infants and healthy adults, but not in patients with spinal cord injury [9,10], and it is not clear how patients with spinal cord injury (mainly with paraplegia) perform quadruped movement. Therefore, clarification of the characteristics of the quadruped movement of patients with spinal cord injury may contribute to the development of the rehabilitation of trunk function. The objective of this study was to confirm the characteristics of quadruped movement of patients with paraplegia using a three-dimensional motion analyzer.

Methods

Participants and ethical considerations

The participants were those with complete paraplegia (regardless of the cause of injury) who were able to perform the quadruped movement. Among patients with paraplegia, we excluded patients with severe complications (e.g., heart disease, pressure

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Table 1. *Patients information*

Case	Age/Sex	Disease	NLI	ASIA		WISCI II (Braces)	Remarks
				AIS	LEMS (Rt./Lt.)		
A	22/F	Traumatic SCI	L1	A	10/3	12 (Rt.AFO, Lt.KAFO)	Hard to move left leg
B	28/M	Traumatic SCI	L1	A	0/0	5 (both side KAFO)	Hard to move right leg
C	29/F	Spinal Cord Tumor	Th10	A	0/10	9 (both side KAFO)	Hard to move right leg

Note: F; Female, M; Male, NLI; Neurological Level of Injury, ASIA; American Spinal Injury Association, AIS; ASIA Impairment Scale, LEMS; Lower Extremity Motor Score, WISCI II; Walking Index for Spinal Cord Injury, AFO; Ankle Foot Orthosis, KAFO; Knee Ankle Foot Orthosis.

ulcers) and those who could not perform wheelchair-to-floor transfer. Similarly, we excluded patients who did not agree to participate in the study or those whose doctors/rehabilitation staff judged them as inappropriate for the study. We included 3 patients with paraplegia (1 male, 2 females, age 26.3±3.79 years old) (see Table 1). This study was conducted by the Declaration of Helsinki. The contents and risks of the study were provided in writing and verbally to the participants and all participants provided consent before the study began.

Data acquisition and processing

The measurement equipment included a three-dimensional motion analyzer VICON GIGANET (Vicon Motion Systems; MX T20-S, 8 cameras) and a ground reaction force plate (AMTI; OR6 series, 6 plates). Markers included acromial processes, humeral lateral epicondyles, ulnar styloid processes, 5th metacarpal heads, anterior superior iliac spines, posterior superior iliac spines, hip joints (1/3 of the distance from the linear trochanter side connecting the anterior superior iliac spines and the greater trochanter), knee joints (center of anteroposterior diameter of knee excluding patella at the height of the outer epicondyle of the femur), foot joint points (lateral malleolus), the 5th base of metatarsal bones, calcaneal bones, and 4 points of head (on the same horizontal plane), the sternal notch, the xiphoid process, 7th cervical and 10th thoracic spinous processes; in total, 30 points were added. The thoracic coordinate system was set using markers on the sternum, xiphoid process, and the 7th cervical and 10th thoracic spinous processes. The pelvic coordinate system was set using the left and right anterior superior iliac spines as well as the posterior superior iliac spines as markers. On the thoracic coordinate system, the origin was defined as the midpoint between the 10th thoracic spinous processes and the xiphoid process, while the vector from the origin to the xiphoid process was defined as the Y-axis. The cross-product of the vector from the midpoint between the sternal notch and 7th cervical spinous processes to the origin and the Y-axis was defined as the Z-axis. Similarly, the cross-product of the Z-axis and the Y-axis was defined as the X-axis. On the pelvic coordinate system, the midpoint of the left and right anterior superior iliac spines was the origin, and the vector from the midpoint of the left and right posterior superior iliac spines to the origin was the Y-axis. The cross-product of the vector from the origin to the right anterior superior iliac spines and the Y-axis was the Z-axis, while the cross-product of the Y-axis and the Z-axis as the X-axis. The angles of the thoracic coordinate system and the pelvic coordinate system in the absolute coordinate system were defined as the thoracic angle and pelvic angle, respectively.

While performing quadruped movements, it is difficult to recognize markers on the front of the thoracic and the pelvis (floor side); therefore, an additional marker was affixed to the 7th costal arches and iliac crests. In the standing position, we recorded the relative position of the segment, which was defined by markers of the 7th cervical and 10th thoracic spinous processes, 7th costal arches, with respect to the sternal notch and xiphoid. The relative position of the segment was defined by markers of the posterior superior iliac spines and iliac crests, continuing to the anterior superior iliac spines. When measuring quadruped movements, we calculated the markers of the sternal notch and xiphoid recorded during movement, using the relative position, from the segment defined by markers of the 7th cervical and 10th thoracic spinous processes, and the 7th costal arches, with respect to the sternal notch and xiphoid processes that were recorded during standing. In addition, we calculated the markers of the posterior superior iliac spines during movement, using the relative position, from the segments defined by posterior superior iliac spines and the iliac crest, to the anterior superior iliac spines, during standing.

The quadruped movement was measured 2 times on the 4-m path by physical therapist. One cycle of the quadruped movement was defined as "left-hand contact to left-hand contact again". In addition, we did not specify the mode of movement for quadruped movement. And all patients has experienced quadruped movement in physical therapy.

Outcome measures

Gait pattern of rats with paraplegia classified in six ways [11]. Based on the classification, the order of moving the limbs was evaluated in quadruped movement. In addition, in this study, the indicators included the number of limbs that touched the ground during quadruped movement, the time from movement of one limb to the movement of the next limb, and the number of limbs that were supported during gait using the parallel bars. The number of limbs grounded and the time between grounding of the limbs was judged based on the ground reaction force. Therefore, if multiple ground reaction forces were combined, it was difficult to determine the limb grounding and raising. Therefore, the period in which one limb was grounded with a different plate was noted. In particular, the period in which the right hand and right knee (or left hand and left knee) was grounded with the same plate was excluded. For example, the muscle activity of the lower limb is innervated at the lower lumbar and sacral levels. Therefore, the ability to control the alignment of the pelvis via the upper limbs and trunk is required in patients with paraplegia. Accordingly, we extracted the rotation and the side flexion angle of the thoracic and pelvic levels during the quadruped movement. Using these two outcome measures, we confirmed the movement patterns of quadruped movement.

Statistical analyses

Since this study is a case series with a small number (3) of cases, specific statistical tests were not run. We verified how to move the limbs in quadruped movement by looking at the stick pictures. Moreover, the control of the thoracic and pelvic movement was verified by each lateral bending and rotation angle graph.

Results

Table 2 shows the time required for one cycle of quadruped movement. Furthermore, Figure 1 shows the graph of the rotation and the side flexion angle of the thoracic and pelvic levels, and the timing of grounding and raising for each limb. Case A demonstrated two-point movement in the upper and lower limbs that occurred reciprocally. Additionally, cases B and C demonstrated cycles of four-point and three-point movement, respectively, which also occurred reciprocally.

Movement of the upper and lower limbs

Figure 2 shows a stick picture with the upper limb raised during the quadruped movement. Table 3 shows the length of time between upper limb raising and contralateral lower limb raising in all cases. In case A, the left knee was raised with the right knee almost simultaneously, but there was a slight time difference between the raising of the left hand and the right knee. In cases B and C, although there was a difference between the sides, the right hand or left hand was raised while loading occurred on the contralateral knee.

Table 2. *Time required for one cycle of quadruped movement [s]*

	Case A	Case B	Case C
Time	2.75±0.30	4.53±0.50	4.27±0.72

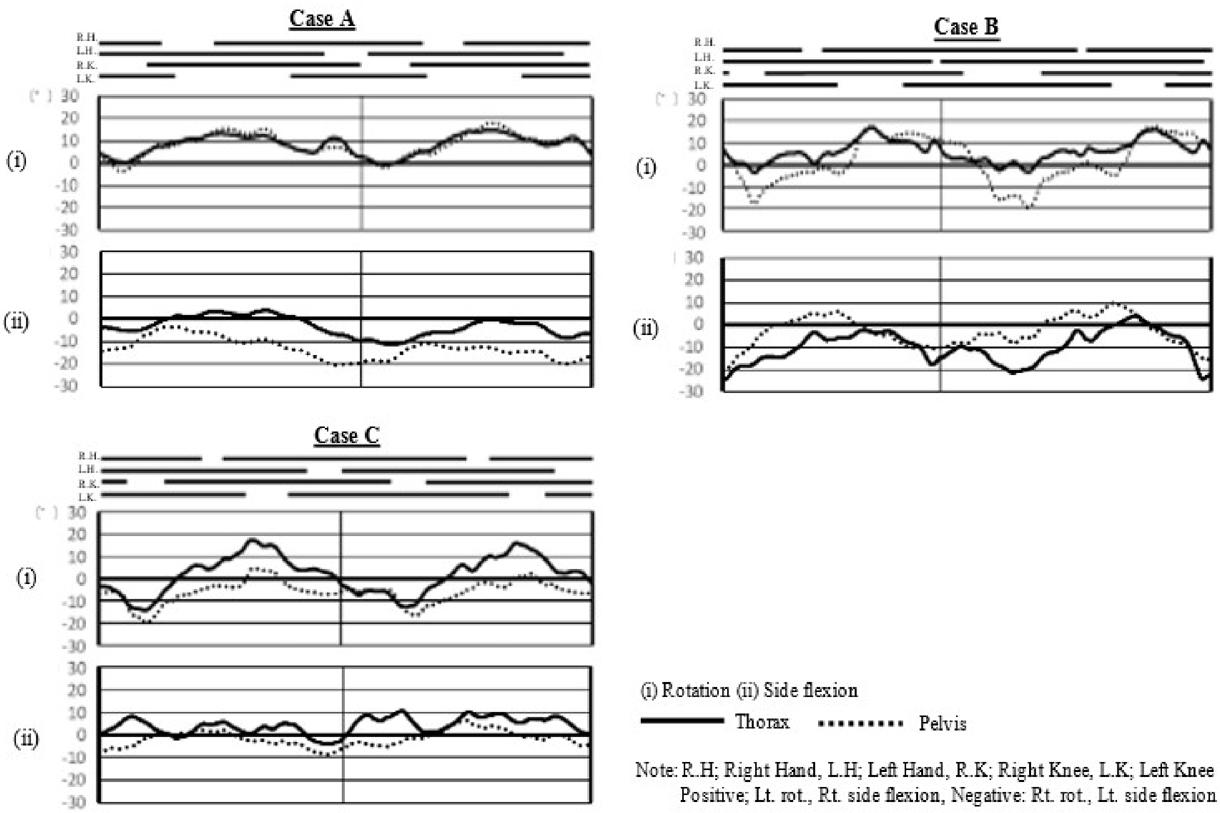
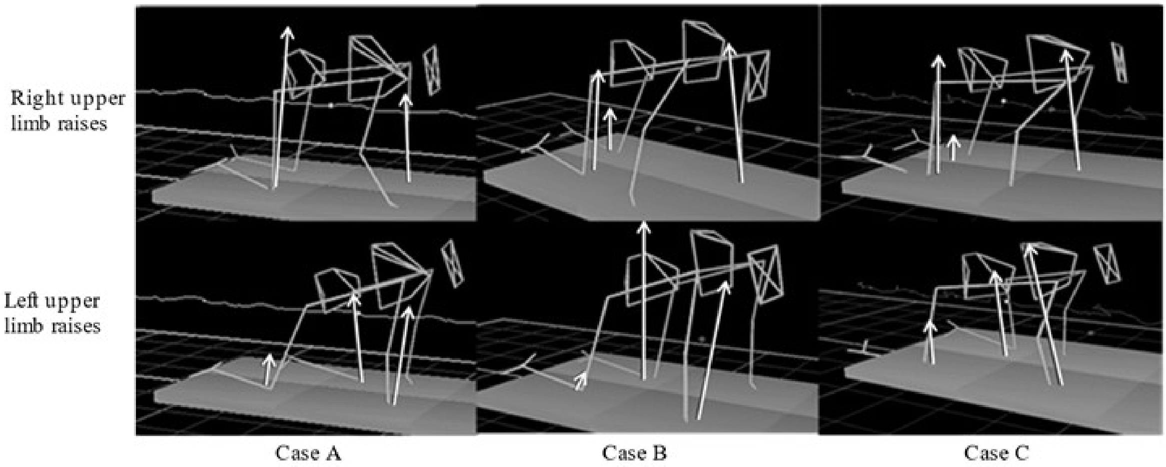


Figure 1. *Timing of rotation and side flexion of thorax and pelvis in quadruped movemnet*



Note: the magnitude of the floor reaction force has been tripled

Figure 2. *The stick picture when raise hand of each patients in quadruped movement*

Table 3. *The time from raising the hand to raising the contralateral knee [s]*

Case	right upper limb to left knee	left upper limb to right knee
A	0.07 ± 0.01	0.16 ± 0.02
B	0.65 ± 0.22	0.44 ± 0.40
C	0.74 ± 0.11	0.63 ± 0.01

Movement of the thorax and pelvis

In patients with paraplegia, the rotational angle of the thoracic and pelvic levels peaked at the same time and on the same side of the knee being raised (Figure 1). In case A, the right-sided flexion of the thorax and pelvis was not observed due to the left pelvic rotation observed when raising the left knee. Right pelvic rotation did not occur, and the thorax and pelvis were flexed to the left. In case B, the right rotation of the thorax was larger than that of the pelvis while raising the right knee, but the thorax was flexed more to the left than the pelvis. There were no significant differences in the rotation of the thorax and pelvis and the side flexion angle when raising the left knee. In case C, while raising the right knee, the thorax had a slightly smaller right rotational angle than the pelvis; notably, the thorax was flexed to the right. Furthermore, when raising the left knee, the thorax had a larger left rotational angle than the pelvis.

Discussion

In the rehabilitation of patients with spinal cord injury, we often use the quadruped movement [4,6-8]. However, no reports of biomechanical analysis on quadruped movement in patients with spinal cord injury. Therefore, this study is the first report on the biomechanical study of quadruped movement in patients with spinal cord injury and may contribute to the performance of quadruped movement in patients with spinal cord injury.

In this study, we measured quadruped movements using a three-dimensional motion analyzer and ground reaction force plate. The quadruped movement was like the walk and trot used for the movement of quadrupeds. In particular, the movement was like the trot for case A, and like the walk for cases B and C. The gait speed of humans increases gradually, shifting from walking to running when the critical point is exceeded [12]. Furthermore, when the walking speed of a quadruped horse is increased gradually, beyond the critical point, the energy efficiency is higher with the trot than with the walk [13]. In this study, case A has higher physical function (gait ability) than cases B and C, and it is considered that a trot-like movement was used instead of the walk in order to perform quadruped movement more efficiently. In other words, when evaluating the gait of patients with paraplegia, it may be necessary to evaluate not only physical functions such as NLI, AIS, and muscle strength, but also whether two-point support in quadruped movement is possible. In addition, in patients with paraplegia, the thorax and pelvis always rotated ipsilaterally on both quadruped movement (Figure 3). Therefore, the rotation of the thorax and pelvis occurred mainly on the same side as the raised knee in quadruped movement. This is most likely because the weight of the lower limb held in space cannot be stably supported by the other three limbs, but it is thought to be a reaction to rotate to the same side and place the center of gravity within the base of support as much as possible. In other words, to move the lower limbs, which usually do not voluntarily swing, rotating of the thorax and pelvis occur to ensure clearance and compensate for the lack of swinging. Therefore, it can be inferred that the voluntary leg movement and the rotation of the thorax and pelvis and the side flexion interfere with each other in quadruped movement in patients with paraplegia. Therefore, the movement of upper and lower limbs and trunk rotation during quadruped movement may be an important index to evaluate quadruped movement.

Figure 3. *The rotation of the thorax and pelvis in quadruped movement of patient with paraplegia*

Limitations

Despite our findings, there are some limitations that should be addressed. The quadruped movement is identified as a developmental movement patterns of infants and Activity-Based Therapy, but there are no known reports that have collected objective data; therefore, the environmental setting and outcome measures used in the present study may not be appropriate. Additionally, since sample size is small, generalized for other NLI and AIS cases. Therefore, future studies should include parameters necessary for more accurate verification (such as the position of the center of gravity, moving speed, and electromyogram data), and a larger number of cases.

Conclusion

In this study, we confirmed the characteristics of quadruped movement in patients with paraplegia. Based on our findings, our results suggested that patients with spinal cord injury have an ipsilateral rotation of the pelvis when moving the lower limbs in quadruped movement. Also, it seems that, depending on the degree of disability, some cases were able to move the contralateral upper and lower limbs simultaneously, while others moved one limb at a time.

Declaration of interest

Authors state no conflict of interest.

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