

## Biomechanical investigation of ambulatory training in patients with acetabular dysplasia

### Abstract

The purpose of this study was to investigate the effectiveness and safety of ambulatory training in patients with acetabular dysplasia. To do this, we clarified the hip joint moment when subjects walked with laterally and horizontally elevated arms and changing speeds as training to strengthen hip joint abductor muscles during walking. The subjects were eight women with pre- or early stage hip disease (center–edge angle of Wieberg  $18.5^{\circ}$  –  $-3.0^{\circ}$ ) and six healthy women. In exercise task 1 the subjects walked at a rate of 90 steps/minute, with abduction of  $90^{\circ}$  in the shoulder joint ipsilateral or contralateral to the affected hip joint, and either no load or a 1 kg weight in either hand. In exercise task 2, walking speed was changed in three stages from 60 steps/min (s-gait), 90 steps/min (n-gait), and 120 steps/min (f-gait), with both hands swinging freely. Using results from a three-dimensional motion analysis system, the hip joint moments were calculated. In both the healthy group and the acetabular dysplasia group, the abduction moment of the hip joint decreased significantly with ipsilateral elevation and increased significantly with contralateral elevation. There was no significant difference in the flexion moment of the hip joint in both groups. The extension moment of the hip joint decreased significantly with contralateral elevation, but no significant differences were seen in ipsilateral elevation. In the walking rate variation, the extension moment of the hip joint in f-gait was higher than s-gait. It was suggested that ambulatory training with contralateral horizontal arm elevation has a possibility of being an effective way to increase hip joint abductor muscle strength in the stance phase. Ipsilateral arm elevation which decreases gluteus medius muscle tension is an effective means of ambulatory training for people with compensated trendelenburg gait. Variable speed walking is an effective exercise method that can strengthen extensor muscles. Therefore, each ambulatory training method is useful for acetabular dysplasia patients.

### Introduction

Osteoarthritis of the hip is a disease that leads to deformation of the joint caused by degeneration and wear of the hip joint cartilage. The etiology is varied, but can be divided into idiopathic osteoarthritis and secondary osteoarthritis ascribable to underlying diseases. Many cases are seen in which acetabular dysplasia is the cause of secondary osteoarthritis of the hip joint, and various conservative or operative therapies are conducted. In either case, physical therapy procedures, such as range of motion exercises to prevent or treat contracture, or strength training or weight-bearing ambulatory training to prevent or improve musculoskeletal disuse atrophy are carried out. One of the most important aims is to improve walking ability in people with osteoarthritis of the hip joint.

Clinical signs of hip osteoarthritis are pain, muscle atrophy, reduced range of motion and abnormal gait. In acetabular dysplasia, surgery is often indicated. Osteotomy with realignment of the pelvis is performed to improve stability and increase surface area for weight bearing purposes. On the other hand, functional activity training, muscle exercise, modalities for relieving pain and aerobic conditioning are often conducted as part of the physical rehabilitation of a painful and/or unstable hip. Such treatment was done for patients who had hip joint operations and for patients who had not been operated on. However, in spite of such treatments, some patients still have deviation in gait. There are three reasons for these deviations in gait. First, they could not activate the hip joint abductor muscles at the suitable timing in the stance phase, because they had leaned to accommodate the compensatory lean to the weak side in gait. Second, prolonged weakness in the hip abductor muscles which was caused by the insufficient treatment. Third, coxalgia occurred by the excessive load. Improving ambulatory ability requires not only strengthening the muscles necessary for walking but also the timing of muscle activation, based on the overload and task specific principles. Therefore, it is especially important to strengthen the hip joint abductor muscles, which requires not only hip joint abduction exercise in a recumbent position, but also standing and walking exercises.

#### Objective

The purpose of this study was to establish indicators for safe and effective

physical therapy methods for the people with acetabular dysplasia, through clarifying the effects of ambulatory training with lateral horizontal arm elevation or variable speed walking to regulate the amount of abductor muscle loading during walking, and strengthen the abductor muscle and improve gait posture.

### Subjects and methods

The subjects were eight women with pre- or early stage osteoarthritis caused by acetabular dysplasia (Acetabular dysplasia group; mean age  $37.3 \pm 9.7$  years, mean center–edge angle of Wieberg[1]  $9.7^\circ \pm 6.9^\circ$ :  $18.5^\circ$  to  $-3.0^\circ$ ). They could walk without a cane, and have no pain. Six healthy women who had unimpaired limb movement function and did not exercise regularly (mean age  $27.3 \pm 1.8$  years) were the healthy group. They all understood the study and consented to participate.

There were two exercise tasks, as described below.

#### Walking task 1 (Fig. 1)

The trial subjects walked with one shoulder joint in a position of  $90^\circ$  abduction and no load or holding a 1 kg weight in the hand. The walking rate was prescribed at 90 steps/min. The subjects walked with lateral horizontal elevation of the arm ipsilateral (no load ip-gait, 1 kg elevated ip-1-gait) and contralateral (no load con-gait, 1 kg elevated con-1-gait) to the affected hip.

#### Walking task 2

The subjects walked at three different rates of 60 steps/min (s-gait), 90 steps/min (n-gait), 120 steps/min (f-gait), with both hands swing free. A metronome was used to adjust cadences. Walking patterns were not affected within these prescribed speeds.

As for walking measurements in both tasks 1 and 2, subjects were made to walk barefoot on a 10-meter walking course. A two-piece force plate, two meters in length (Kistler), and a 3-dimensional motion analyzer (Vicon 250; Oxford Metrics) were used. A total of fifteen reflective markers were attached to the acromions, anterior superior iliac spines, greater trochanters, lateral epicondyles, lateral malleoluses, 5th metatarsal heads, heels and the mid point between the posterior superior iliac spines. A position of the hip joint was decided by the method of Seidel [2]. As the knee joint and ankle joint were set to a single axis

(flexion and extension), the rotation between the tibia and the femur was not measured.

From the movement measurement results, the hip joint flexion-extension and abduction-adduction moments were calculated using rigid link models referred to Winters [3], and a comparison was made between conditions with the reference to 90 steps/min (n-gait).

In the statistical analysis, two-way analysis of variance was used for inter- and intra-group comparisons, and Bonferroni's method was used in multiple comparisons within each group.  $P < 0.05$  was taken to be the level of statistical significance.

## Results

Figure 2 shows the changes in hip joint moment in the stance phase when subjects walked with elevation of the arm ipsilateral to the affected hip. Table 1 shows the maximum values for each hip joint moment when subjects walked with elevation of the arm ipsilateral to the affected hip. In both the healthy and acetabular dysplasia groups, the hip joint extension and flexion moments in the stance phase had no significant differences in walking tasks. Hip joint abduction moment was significantly lower with the ip-1-gait than with the n-gait. No significant difference was seen in a comparison of the healthy and acetabular dysplasia groups.

Figure 3 shows the changes in hip joint moment in the stance phase when subjects walked with elevation of the arm contralateral to the affected hip. Table 2 shows the maximum values for each hip joint moment when subjects walked with elevation of the arm contralateral to the affected hip. In both the healthy and acetabular dysplasia groups, the hip joint extension moment in the stance phase was significantly lower with both the con-gait and the con-1-gait than with the n-gait. Hip joint abduction moment was significantly higher with the con-1-gait than with the n-gait. No significant difference was seen in a comparison of the healthy and acetabular dysplasia groups.

Figure 4 shows the changes in hip joint moment in the stance phase when subjects walked in variable speed. Table 3 shows the maximum values for each hip joint moment when subjects walked in variable speed. In both the healthy

and acetabular dysplasia groups, the hip joint extension moment in the stance phase was significantly higher with the f-gait than with the s-gait. In the acetabular dysplasia groups, the hip joint abduction moment was significantly higher with the f-gait than with the s-gait. A comparison of the two groups revealed significantly lower hip joint extension moment in the acetabular dysplasia group.

## Discussion

Arokoski et al.[4] reported on the range of motion and physical function of the hip joint with early stages of hip osteoarthritis and compared the results with those from a control group. The control group subjects were significantly better at marching on-the-spot, ascending and descending stairs, and 25-m walk compared with the hip osteoarthritis patients. In addition, the controls were significantly better at the range of motion. Therefore, it is necessary for the patients with hip osteoarthritis to improve movement ability such as walking, through rehabilitation for the recovery of the hip joint function.

Watelain et al.[5] reported that increasing pelvic tilt and inclining the trunk on the side of the supporting limb allows osteoarthritis subjects to shorten the moment arm between hip and center of mass of the upper body. Even at an early stage of hip osteoarthritis, subjects in the clinical group developed a gait strategy to minimize the load on their painful hip. Nicholas et al.[6] reported a close relationship between hip abductor strength and the results of the Trendelenburg test. These observations well expressed the problems of the hip osteoarthritis patients. As the degeneration progresses, the patients lean their trunk to the affected side to reduce muscle load and hip joint stress. Leaning the trunk to the affected side decreases the moment arm between the center of mass and the hip joint, as a result, reduces the torque necessary to keep pelvis stable. Especially, It reduces the abductor muscle force that plays an important role at the stance phase and prevents pain

Neumann et al. [8,9] had subjects hold a load on the same side as the load-bearing leg during the stance phase, and reported decreased gluteus medius activity. When the load was on the contralateral side, however, the activity increased. Bergmann et al. [10,11] calculated hip joint load on the frontal

plane based on the simplified model of Pauwels, and reported increased hip joint resultant force with contralateral arm elevation or a weight load, including a comparison with the results using an artificial femoral head with imbedded force sensors.

Arokoski et al.[4] reported that osteoarthritis treatment, if it is to be successful, should be initiated before the stage of osteoarthritis when irreversible cartilage loss can be visualized on radiographs as a narrowing of the joint space. In addition, Yasunaga[12,13] reported that the reduction of the sharp pain and improvement of muscle strength are often seen with the patients after osteotomy. However, he also reported that some patients still walked leaning the trunk to the operated side, even if their muscle strength was improved. One of the reasons was that the muscles of the hip joint might not be activated at the suitable timing for the stance phase. Because of this mis-timing, patients must be trained to exert proper muscle strength while walking.

The present results showed that in both the control and acetabular dysplasia groups, the hip joint abduction moment decreased with ipsilateral arm elevation, and increased with contralateral arm elevation. This is believed to be because arm elevation causes the body's center of mass to shift to the elevated arm side. This indicates the effectiveness of the present method for ambulatory training that increases and decreases the load, during the stance phase. In addition, in patients for whom the center of mass is moved to the affected side by bending the trunk toward the affected side in the stance phase as a result of weakened gluteus medius, the load on the muscle is lightened by raising the ipsilateral arm. As a result, ambulatory training can focus on the avoidance of leaning the trunk to the side of the weakness. Moreover, despite postoperative recovery of hip joint abductor muscle strength, the gluteus medius muscle does not activate with good timing in the first half of mid-stance. In such a case, the ipsilateral arm elevation also help to avoid leaning the trunk.

The hip joint extension moment decreased with contralateral arm elevation, due to the floor reaction force vector passed by the hip joint due to the decrease in the pelvis rotation in horizontal plane.

The hip joint extension moment decreased with s-gait, and increased with f-gait. Neumann pointed out that in early stance, the hip muscles generates a hip

extension torque that serves to accept the weight of the body, to control the trunk and to extend the hip. In this study, the hip joint extension moment was related to the acceleration of the center of gravity at the stance phase. Therefore, the ambulatory training in slow speed is better suited for patients with weak hip joint muscle.

The reason why the hip extension moment in the acetabular dysplasia groups is smaller than healthy group is that they might reduce extension moment in order to decrease the hip joint load at the heel contact.

It was suggested that the ambulatory training with horizontal arm elevation and changing speeds during walking has a possibility of being an effective way to train and strengthen hip joint muscles in the stance phase.

## Conclusions

It was suggested that the ambulatory training with contralateral horizontal arm elevation has the possibility of being an effective way to increase gluteus medius muscle strength in the stance phase. Ipsilateral arm elevation which decreases gluteus medius muscle tension is an effective means of ambulatory training for people with compensated Trendelenburg gait. Similarly, changing speeds during walking has a possibility of being an effective method in the ambulatory training. In the future it will be necessary to conduct further investigations for cases of severe acetabular dysplasia.

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