Periacetabular osteotomy reduces the dynamic instability of dysplastic hips

A. Maeyama, M. Naito, S. Moriyama, I. Yoshimura
From Fukuoka University, Fukuoka, Japan

We compared the dynamic instability of 25 dysplastic hips in 25 patients using triaxial accelerometry before and one year after periacetabular osteotomy. We also evaluated the hips clinically using the Harris hip score and assessed acetabular orientation by radiography before surgery and after one year. The mean overall magnitude of acceleration was significantly reduced from 2.30 m/s² (SD 0.57) before operation to 1.55 m/s² (SD 0.31) afterwards. The mean Harris hip score improved from 78.08 (47 to 96) to 95.36 points (88 to 100). The radiographic parameters all showed significant improvements.

This study suggests that periacetabular osteotomy provides pain relief, improves acetabular cover and reduces the dynamic instability in patients with dysplastic hips.

Dysplastic hips may progress to osteoarthritis. Several factors, including excessive loading of the cartilage, dynamic instability and muscular fatigue,1-6 may contribute to this. We consider mechanical stress and dynamic instability to be the major factors.7 Lateral thrust associated with a shift of load when walking is considered to be the main cause of osteoarthritis of the knee joint.8-10 Sutherland and Greenfield11 noted that instability in dysplastic hips was evident in push-pull radiographs taken during arthrography. In a cadaver study, Wingstrand, Wingstrand and Krantz12 found that the traction force required to overcome the stabilising effect of atmospheric pressure and subluxate the adult joint was approximately 200 N, and proportional to the square of the diameter of the femoral head. They also proposed that intra-capsular fluid made the joint potentially unstable, a pre-requisite for unfavourable mechanical loading of the cartilage. It is therefore thought that instability is an important factor in the onset of secondary osteoarthritis of the hip joint.

In Japan, almost 80% of cases with osteoarthritis of the hip joint are secondary to developmental dysplasia.5 Various types of periacetabular osteotomy are used in patients who are too young for total hip replacement.13-19 We perform a curved periacetabular osteotomy,16 which is a modification of the Bernese periacetabular osteotomy developed by Ganz et al.13 Although many reports have shown that periacetabular osteotomy can reduce contact stress in the hip joint,20-24 none have clarified whether it can also reduce instability during walking in daily life. After our previous study7 we hypothesised that dynamic instability of the hip joint would be reduced if the cover of the femoral head was improved by periacetabular osteotomy. We therefore compared the dynamic instabilities of dysplastic hips before and after periacetabular osteotomy.

Materials and Methods
We evaluated 25 hips in 25 patients with dysplastic hips and a centre-edge angle of < 25° who underwent curved periacetabular osteotomy. There was one man and 24 women with a mean age of 32.1 years (14 to 56). Patients with functional, neurological or morphological disorders affecting gait were excluded from the study. We also excluded those with collagen disease or other disorders causing hyperlaxity of the joint. Obese patients were excluded owing to difficulties with measurements of instability, as mentioned below. The arthritis of the affected hip was limited to grade 0 or 1 according to the Tönnis classification.25 All contralateral hips were disease free, with normal radiographic findings of a centre-edge angle of ≥ 25°. The knees and ankles in both limbs were disease free, with normal radiological findings. The pre-operative breakdown of the centre-edge angles showed 12 hips ≤ 10° and 13 hips ≥ 11°. The study was approved by our Institutional Review Board and each patient gave informed consent.
against the skin as described previously,\textsuperscript{32,33} and excluded osteometers are attached, we pre-loaded the accelerometer movement, which are commonly produced when accelerometers are attached to the skin over the greater trochanter bilaterally. In an attempt to minimise artefacts due to skin movement on a body segment in three dimensions from data obtained using an accelerometer.\textsuperscript{27,28} Several studies have used accelerometry for the quantitative analysis of hip instability, using the formula \(a = \sqrt{(ax^2 + ay^2 + az^2)}\). The overall magnitude of acceleration of the dysplastic hip before operation was compared with that one year later.

\textbf{Diagram showing how an accelerometer was used to record triaxial acceleration while walking (x-axis: superoinferior direction; y-axis: anteroposterior direction; z-axis: mediolateral direction). Sensors were attached to the skin over the greater trochanter bilaterally.}

**Analysis by accelerometry.** Accelerometry was originally used in human movement analysis in 1973,\textsuperscript{26} and has since been developed to calculate the total resultant force and movement on a body segment. Several studies have used accelerometry for dynamic analysis of hip joints.\textsuperscript{29-31} The reliability, accuracy and reproducibility of evaluating hip instability using accelerometry have been demonstrated in previous studies.\textsuperscript{8-10} We have described the use of accelerometry for the quantitative analysis of instability of the hip during walking.\textsuperscript{7} In this study we used this technique to compare instability in hips before and at one year after the operation. An accelerometer (Kistler, Postfach, Switzerland) was used to record triaxial acceleration during walking with the x-axis recording the superoinferior direction, the y-axis the anteroposterior (AP) direction and the z-axis the mediolateral direction (Fig. 1). Using adhesive tape we attached the sensors to the skin over the greater trochanters and anterior superior iliac spines because the subcutaneous tissue is thin at these sites and they are easily palpable. In an attempt to minimise artefacts due to skin movement, which are commonly produced when accelerometers are attached, we pre-loaded the accelerometer against the skin as described previously.\textsuperscript{32,33} and excluded patients with a body mass index (BMI) of $> 25$ kg/m\textsuperscript{2}. In order to exclude the influence of pelvic movement, sensors were attached to the skin over the anterior superior iliac spine on both sides as reference points. The time of heel strike was confirmed visually and by superoinferior acceleration. Signals from the sensors were recorded as digital data through an analogue/digital board. The sampling rate was 10 kHz. Each patient completed three repetitions of walking for each hip, and care was taken to ensure that they had sufficient practice to maintain an even gait. The patients walked for about ten gait cycles on a level walkway at their usual speed wearing their own shoes.

**Data analysis.** The mean peak values of the middle three gait cycles were used for data analysis. The overall magnitude of acceleration was calculated to evaluate hip instability, using the formula \(a = \sqrt{(ax^2 + ay^2 + az^2)}\). The overall magnitude of acceleration of the dysplastic hip before operation was compared with that one year later.

\textbf{Curved periacetabular osteotomy.} The indications for curved periacetabular osteotomy included a patient with a dysplastic hip with symptoms for more than five months, a lateral centre-edge angle of Wiberg\textsuperscript{24} of $< 16^\circ$ on AP radiographs, and an improvement of joint congruency on an AP radiograph in abduction. It was indicated for patients who had a widened or regular joint space in abduction on a pre-operative radiograph of the hip. All the operations were performed by the senior author (MN). The osteotomy was carried out through an anterior approach as previously described.\textsuperscript{16} A dual anterior approach for this procedure has recently been recommended.\textsuperscript{34} The gluteus muscles were not stripped from the iliac bone, thereby preserving the blood supply to the acetabular fragment and enabling smooth reorientation because the osteotomy surfaces had the same curvatures. The skin incision was approximately 12 cm long. The lateral femoral cutaneous nerve was dissected free from the surrounding connective tissues. After osteotomy of the anterior superior iliac spine, it was retracted medially with the sartorius muscle attached. The iliacus muscle was detached and a C-shaped osteotomy line was marked from the anteroinferior iliac spine to the distal part of the quadrilateral surface. An osteotomy of the quadrilateral surface was carried out first using a curved osteotome, and the ischium, superior pubic ramus and ilium were then divided. The acetabular fragment was reoriented anteriorly, laterally and medially, and fixed with two or three screws. We then assessed the range of movement in the hip joint. When flexion was limited we reduced the anterior reorientation of the acetabular fragment to avoid femoroacetabular impingement. Partial weight-bearing mobilisation was started on the third post-operative day. Weight-bearing was increased by 10 kg every two weeks, and full weight-bearing was allowed after eight weeks.

\textbf{Clinical and radiographic assessment.} We evaluated the hips clinically before and one year after operation using the Harris hip score, and radiographically by assessing acetabular orientation using the centre-edge angle, the acetabular roof angle (modified from Massie and Howorth\textsuperscript{35}), the
Sharp angle and the acetabular head index. All measurements were performed by the first author (AM). The radiographic measurements were repeated three times on different days, and the median values were used.

Standard AP radiographs of the hip were taken on the day of examination. The subjects lay supine with their limbs in neutral, and underwent abduction, adduction and rotation of the femur. The tube-to-film distance was 120 cm, and the tube was orientated perpendicular to the table. The centre beam was directed to the midpoint between the upper border of the symphysis and a horizontal line connecting the anterior superior iliac spines. We used the method described by Siebenrock, Schoeniger and Ganz and Siebenrock, Kalberman and Ganz to judge the extent of pelvic inclination.

Statistical methods. Non-parametric statistical analyses were performed using StatView 5.0 for Windows OS. We compared the overall magnitude of acceleration and the clinical and radiographic data of the hips before operation with the corresponding values afterwards using the Mann-Whitney U test. The significance level of these analyses was 5%. The power analysis was performed using G Power 3.0.10 for Windows OS.

Results
In all cases, acceleration when walking was only observed in the superior (x-axis), posterior (y-axis) and lateral (z-axis) directions. The mean pre-operative magnitudes of the triaxial components were 1.45 m/s² (SD 0.63) (x-axis), 0.83 m/s² (SD 0.45) (y-axis) and 1.36 m/s² (SD 0.61) (z-axis) respectively. The mean post-operative magnitudes of the triaxial components were 1.07 m/s² (SD 0.42) (x-axis), 0.80 m/s² (SD 0.20) (y-axis) and 0.67 m/s² (SD 0.26) (z-axis) respectively. The mean overall magnitude of acceleration was significantly reduced from 2.30 m/s² (SD 0.57) before operation to 1.55 m/s² (SD 0.31) afterwards (p < 0.0001, Table I). The mean Harris hip score improved from 78.08 points (47 to 96) to 95.36 points (88 to 100). The mean centre-edge angle, Sharp angle, acetabular roof obliquity and acetabular head index all showed significant improvements (p < 0.0001, p < 0.0001, p < 0.0001 and p < 0.0001, respectively, Table II) compared to their pre-operative values. Joint deterioration was not observed after operation in any patient.

The waveforms of the acceleration signals obtained from both reference points at the anterior superior iliac spines were almost flat in all directions. The pre- and post-operative data of a 17-year-old woman are shown in Figure 2.

Discussion
The relationships between residual hip dysplasia and subluxation and progressive secondary degenerative arthritis are well established. The major factors are mechanical stress and dynamic instability, and if these are not improved after surgery the outcome will not be good. Although many reports have shown that periacetabular osteotomy can reduce contact stress in the hip joint, no studies have clarified whether it can also reduce instability of the hip joint during routine walking. Our results indicate that the femoral head moves in the superior, posterior and lateral directions while walking under conditions encountered in routine daily life, and that mechanical stress to the acetabulum can be expected in the posterosuperior direction in all cases. The mean overall magnitude of acceleration was significantly reduced from 2.30 m/s² pre-operatively to 1.55 m/s² post-operatively. The post-operative value is nearly the same as that for normal hips (1.520 m/s² (SD 0.161), as shown in our previous study, indicating that the degree of instability was almost reduced to that of normal hips after periacetabular osteotomy. All the radiological data and clinical symptoms were significantly improved.

<table>
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<tr>
<th>Table I. Each magnitude of triaxial acceleration</th>
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<tr>
<td>Direction</td>
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<tr>
<td>x-axis (m/s²)</td>
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<td>y-axis (m/s²)</td>
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<td>z-axis (m/s²)</td>
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<td>Overall magnitude of acceleration (m/s²)</td>
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<td>p &lt; 0.0001 for the difference in overall magnitude of acceleration pre- and post-operatively</td>
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<th>Table II. Post-operatively, all parameters showed improvement (p &lt; 0.0001) compared to their pre-operative values</th>
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<tr>
<td>Parameters</td>
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<tr>
<td>Centre-edge angle (°)</td>
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<td>Sharp angle (°)</td>
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<tr>
<td>Acetabular roof obliquity (°)</td>
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<td>Acetabular head index (%)</td>
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<td>Harris hip score (points)</td>
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We have previously shown that the centre-edge angle correlates strongly with the magnitude of acceleration. This suggests that instability of the hip increases in proportion to the degree of dysplasia, and that the centre-edge angle is the most useful indicator of instability. This and the acetabular head index show the relationship between the acetabulum and the femoral head. In particular, the centre-edge angle indicates the relationship between the centre of the femoral head and the acetabular edge, and we therefore consider it to be the best indicator of the biomechanical state of the hip joint during walking.

The results of various acetabular osteotomies for the treatment of dysplasia have been described. These show that the achievement of sufficient acetabular cover after successful osteotomies correlated well with excellent clinical results. Even though our periods of follow-up have been shorter than those in the other studies, the acetabular cover after osteotomy in this series compared well with that in our previous review. We have previously noted that the mean muscle strengths at one year after operation, as measured by the percentage differences of pre-operative values relative to the post-operative state, were 42.2 Nm (129.6%) for the abductor, 39.4 Nm (131.4%) for the adductor, 48.4 Nm (121%) for the flexor and 45.8 Nm (130.5%) for the extensor, all of which exceeded the pre-operative values before curved periacetabular osteotomy. The good
results in the present study may be due to the preservation of the gluteal muscles.

The current study has several limitations. If the sensor is attached to skin with thick subcutaneous tissue over the bone, it is possible that major deviations may occur in the measurements. As the sensor of the accelerometer was attached to the skin over the greater trochanter, the movement of the femoral head was evaluated indirectly. There is some doubt as to whether movement of the greater trochanter reflects instability of the hip. We took the following measures to reproduce the instability of the femoral head. We selected patients who did not have other problems that might have influenced the result, had very early osteoarthritis and could be trained to walk in a prescribed pattern. In order to exclude the influence of pelvic movement, sensors were also attached to the skin over the anterior superior iliac spine bilaterally as reference points.

We consider that accelerometry is useful for evaluating dynamic instability, and that this study will aid further investigations of instability of the hip joint. Periacetabular osteotomy not only successfully provides pain relief and improves acetabular cover, but it also reduces dynamic instability in patients with dysplastic hips.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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