The cartilage degeneration and joint motion of bipolar hemiarthroplasty

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Abstract

Purpose The outcomes of bipolar hemiarthroplasty for osteonecrosis of femoral head have been disappointing due to cartilage degeneration and osteolysis. We investigated the cartilage degeneration, joint motion, and factors associated with osteolysis.

Methods We retrospectively reviewed 134 bipolar hemiarthroplasties. The wear rate of acetabular cartilage was calculated. The ranges of motion of outer bearing and inner bearing were determined, and the ratio (O/I ratio) was calculated.

Results The mean degeneration rate of acetabular cartilage was 0.34 ± 0.35 mm/year. We could observe that the outer bearing motion was dominant, but decreased over time. In addition, the degeneration rate of cartilage and the decline rate of outer bearing motion of the osteolysis group were significantly higher than those of the control group.

Conclusions Close observation is needed in cases of high degeneration rate of cartilage and rapid decline of outer bearing motion due to possibility of osteolysis.

Introduction

Bipolar hemiarthroplasty was introduced in order to reduce the complications of unipolar hemiarthroplasty, such as hip joint pain, premature degeneration of acetabular cartilage and acetabular protrusion [1–3]. The main objective of the

bipolar design was to minimise cartilage degeneration and erosion. The dual articulation design of bipolar hemiarthroplasty has the advantage that the movement and position of the acetabular cup are ideally positioned to distribute the stress on the hip when it is weight bearing [2]. In addition, the centre of rotation of the inner bearing is located more medially than the centre of rotation of the outer bearing to prevent dislocation. These implants have been widely used to treat femoral neck fracture, intertrochanteric fracture, and osteonecrosis of the femoral head [4–7]. However, although favourable outcomes have been reported in short-to-intermediate-term follow-up studies [2, 8], there is disagreement over the long-term outcomes [4, 9, 10].

The main reasons for the disappointing long-term outcomes are high rates of groin pain, excessive degeneration of acetabular articular cartilage, osteolysis and acetabular protrusion of the bipolar cup. We postulated that the groin pain and cartilage degeneration were associated with the interaction between the acetabular cartilage and the artificial bipolar metal cup, and were the result of degeneration of the acetabular articular cartilage. In addition, the osteolysis caused by wear of the polyethylene between the polyethylene liner and the metal head appeared to be associated with a mode of motion that differed from that expected on theoretical grounds and observed in-vitro.

We therefore evaluated acetabular cartilage degeneration and joint motion of bipolar hemiarthroplasty, and investigated the relationship between osteolysis and two parameters.

Materials and methods

Patients

We reviewed retrospectively a series of 132 patients (154 hips) who underwent primary bipolar hemiarthroplasty for treatment of Ficat-Arlet stage III osteonecrosis of the

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femoral head from January 1994 to December 2005 in a single hospital. Of the 132 patients, 17 were excluded because of loss to follow-up (15 patients) and death (two patients). Therefore, 115 patients (134 hips) were included in the study. The study group consisted of 70 males (82 hips) and 45 females (52 hips). The average age was 45.8 years (range, 25–65 years) and the average follow-up period was 7.9 years (range, 5.0–16.4 years).

Implants and surgery

The bipolar prostheses used in the series included 118 Centrax® (Howmedica, Rutherford, New Jersey) and 16 Multipolar® (Zimmer, Warsaw, Indiana). All implants were uncemented prostheses. The implanted bipolar cups were of the same diameters as the femoral heads. All the operations were performed by a single surgeon (I.-Y.C) using the anterolateral approach. After surgery, prophylactic antibiotics were administered for a week and an elastic bandage and compression stocking were applied to prevent deep vein thrombosis. No patient received medication to prevent heterotopic ossification. With regard to postoperative rehabilitation, standing position was allowed on postoperative (PO) day three, walking with crutches on PO day seven, and full weight bearing after six weeks.

Radiographic evaluation

Radiographic evaluation was performed by two orthopaedic surgeons (Y.-S.K, K.-T.H) who had not participated in the surgery. To verify the interobserver reliability of radiographic evaluation, intraclass correlation coefficient (ICC) was used. This is on a scale of 0 to 1 with 1 being the best reliability. For the radiographic evaluation, the standard radiograph consisted of an anteroposterior (AP) view of the pelvis. On the acetabular side, we assessed osteolysis, defined as loss of trabecular bone or cortical erosion that was not apparent on preoperative radiographs, and protrusion, defined as invasion of the bipolar cup over Kohler's line [11]. On the femoral side, we examined the seven zones of Gruen et al. for radiolucent lines and osteolysis [12]. Evidence of stem loosening was evaluated by measuring implant subsidence and conversion to varus or valgus [13]. To measure acetabular articular cartilage degeneration, we drew a line connecting the teardrops on the two sides of an AP radiograph, dropped a perpendicular line from the centre of the bipolar cup, and measured the vertical and horizontal distances from the teardrops. We calculated the square root of the difference between the value in the postoperative radiograph and the value in the final follow-up radiograph [4]. The rate of acetabular articular cartilage degeneration was calculated by dividing the migration of the bipolar cup by the length of the follow-up period. To evaluate the joint

motion of a bipolar prosthesis, we examined AP views of abduction and adduction stress of the pelvis within five years of the operation and at the final follow-up. We measured the angles of motion of the outer bearing and inner bearing by the following procedures. The angle A(A') was defined by the intersection of a line drawn tangential to the most inferior point of the ischia with a line drawn along the inferior margin of the acetabular component. The angle B(B') was defined by the intersection of a reference line drawn perpendicular to the ischial reference line with a line drawn along the centre of the long axis of the femoral stem. The sum of B and B' defined the total extent of motion of the hip joint while abducted and adducted, while the difference between A and A' established the extent of motion of the outer bearing cup. The extent of inner bearing motion was then calculated as the difference between the total hip joint motion and the outer bearing motion [14]. Finally we calculated the ratio of outer and inner motions (O/I ratio).

Clinical evaluation

Clinical evaluation included Harris hip score, groin pain, thigh pain and complications. The Harris hip score at the final follow-up was graded as excellent (>90), good (80–89), fair (70–79), or poor (<69). The severity of pain was classified into three categories. If the patient could undertake activities without medication, the pain was rated mild; if medication was required for daily activity, it was rated moderate; and if daily life was greatly restricted despite medication, it was rated severe.

Statistics

We used SPSS® version 17.0 for Windows (SPSS Inc, Chicago, IL, USA) for the statistical analyses. We compared demographic variables, acetabular articular cartilage degeneration and O/I ratios at the final follow-up in the osteolysis group and non-osteolysis group using the independent *t*-test for continuous variables and the chi-square tests for categorical variables. A relationship between the O/I ratio and the follow-up year was examined using a Pearson's correlation. After plotting the O/I ratio against the follow-up year, the statistical difference of slope of O/I ratio between two groups was determined using the simple linear regression method. We used Kaplan-Meier survival analysis [15] to estimate survival in relation to radiographic osteolysis. All *p* values were two-sided, and *p* values less than 0.05 were considered statistically significant.

Results

Radiographic outcomes

We observed radiographic osteolysis around the bipolar cup in 11 hips (8.2 %) and protrusion of the bipolar cup in three hips (2.2 %). On the femoral side, we observed focal osteolysis confined to Gruen zones 1 and 7 in three hips (2.2 %) and radiolucency in Gruen zones 3, 4 and 5 in two hips (1.5 %). However, there was no evidence of stem loosening.

Intraclass correlation coefficient revealed good reliability for interobserver measurement of acetabular cartilage wear rate and O/I ratio (ICC of acetabular cartilage wear rate, 0.69; ICC of O/I ratio, 0.74). The average distance of migration of the bipolar cup was 2.26 ± 1.88 mm and the degeneration rate of acetabular articular cartilage was 0.34 ± 0.35 mm/year. The average O/I ratio within five years postoperative was 15.73 ± 7.46 , and at final follow-up it was 11.24 ± 12.09 , demonstrating that motion of the outer bearing decreased over time (Fig. 1). There was a linear relationship ($r = -0.296$, $p < 0.001$) when O/I ratio was plotted against the follow-up year. The relationship was inversely proportional (Fig. 2).

When comparing the results of the osteolysis group and those of the non-osteolysis group, the average wear rate of cartilage in the osteolysis group was 0.98 ± 0.89 mm/year and in the non-osteolysis group 0.29 ± 0.18 mm/year, and statistically significant differences were found between the two groups ($p < 0.001$). In the non-osteolysis group, the average O/I ratio at final follow-up was 12.21 ± 12.15 ; however, in the osteolysis group, it was 0.35 ± 0.18 . There were statistically significant differences between the two groups ($p = 0.002$) (Table 1). When O/I ratios were plotted against follow-up time, the rate of decline of O/I ratio appeared to be higher in the osteolysis group than in non-osteolysis group with statistical significance ($p = 0.009$) (Fig. 2).

Clinical outcomes

The mean Harris hip score improved from 52.1 (range, 23–71) preoperatively to 91.8 (range, 68–99) at final follow-up. Results for 92 hips (68.7 %) were excellent, 31 hips (23.1 %) were good, eight hips were (5.9 %) fair, and three hips (2.2 %) were considered poor. Thigh pain occurred in four hips (2.9 %) and was of mild degree, while groin pain occurred in 18 hips (13.4 %) and involved mild pain in 16

Fig. 1 The serial radiographs of stress abduction and adduction views show the decline of O/I ratio over time. In the abduction (a) and the adduction (b) stress view of 1 year postoperative, the O/I ratio was 9.07. However, in the abduction (c) and the adduction (d) stress view of 15 years postoperative, the O/I ratio was 3.91

Fig. 2 As the follow-up period increases, the O/I ratio decreases (*solid line, $p < 0.001$*). The rate of decline of O/I ratio appeared to be higher in the osteolysis group (*short dashed line*) than in the non-osteolysis group (*long dashed line*)

hips and moderate pain in two hips. There were no significant differences according to the demographic parameters and clinical outcomes between the two groups (Table 1).

Complications

In terms of complications, there were four protrusions of the acetabular cup and the revision total hip arthroplasties were performed. There was a deep infection treated by irrigation and debridement followed by secondary revision. One case of superficial infection was cured with intravenous antibiotics.

Survival analysis

We performed a Kaplan-Meier survival analysis [15] on the 134 hips. When radiographic osteolysis was taken as an endpoint, ten-year survival was 92.0 % (95 % confidence

interval, 88.1–95.9 %) and 16 year survival was 46.7 % (95 % confidence interval, 26.6–66.8 %), reflecting a sharp drop in the survival curve (Fig. 3).

Discussion

Due to the particular benefits of the prosthetic design, several authors have reported outcomes of bipolar hemiarthroplasty comparable to those of total hip arthroplasty. Yamamuro et al. reported good clinical results in a five-year follow-up study [16], and Takaoka et al. reported an 8 % failure rate and favourable short-term and intermediate-term outcomes [17]. In contrast to the generally positive reports, Cabanella et al. reported that bipolar hemiarthroplasty resulted in higher rates of groin pain and worse clinical results than total hip arthroplasty in a follow-up study averaging 9.2 years [9], and Ito et al. reported 42 %

Table 1 Comparison of the demographic and radiographic data of the osteolysis and non-osteolysis groups

Variable	Osteolysis group (n=11)	Non-osteolysis group (n=123)	p-value
Male:Female	7:4	75:48	0.862
Age (years)	51.8±10.1	45.3±11.2	0.066
Body mass index (kg/m ²)	23.6±3.9	24.2±3.4	0.769
Implant (hips)			
Centrax®	10	108	0.761
Multipolar®	1	15	
Harris hip score	88.5	92.1	0.561
Thigh pain (hips)	1	3	0.293
Groin pain (hips)	3	15	0.168
Cartilage wear rate (mm/year)	0.98±0.89	0.29±0.18	<0.001
O/I ratio at final follow-up	0.35±0.18	12.22±12.15	0.002

Values are expressed as mean ± SD or as numbers of patients, as appropriate

Fig. 3 A Kaplan-Meier survival curve for all 134 hips. When radiographic osteolysis was taken as an endpoint, ten-year survival was 92.0 % (95 % confidence interval, 88.1–95.9 %) and 16 year survival was 46.7 % (95 % confidence interval, 26.6–66.8 %), reflecting a sharp drop in the survival curve

groin pain rate and 25 % revision rate in a follow-up study averaging 11.4 years [10]. In our series, we found comparable intermediate-term survival to that of total hip arthroplasty. However, the incidence of groin pain (13.4 %) was relatively high and, when the endpoint was radiographic osteolysis, the survival rate at ten years was 92.0 %, but fell sharply to 46.7 % at 16 years.

The limitations of this study were as follows. First, we chose to focus on radiographic osteolysis. In metal-on-polyethylene articulation, osteolysis can appear at mid-term follow-up. Most surgeons would not perform revision surgery because of minor osteolysis. However, we considered osteolysis to be a warning sign of subsequent implant failure and revision. Second, we investigated the coronal joint motion of the bipolar implants while the joint motion of bipolar implants is three-dimensional. However, we thought that the abduction and adduction stress view on the coronal plane could reflect the outer to inner bearing motion distribution of the bipolar component. Most authors have used this method of evaluation [18]. Third, the rather extensive follow-up period might have influenced the results of the bipolar hemiarthroplasty. However, the majority of the patients were followed-up for between five and 12 years and thus this effect on the results should be limited.

Degeneration of the acetabular articular cartilage after bipolar hemiarthroplasty has been investigated in numerous studies, and various influencing factors have been reported

[19, 20]. The hard bipolar cup delivers abnormal stress to the articular cartilage, and this results in increased secretion of destructive enzymes and influences the biomechanical properties of the cartilage. In our study, the rate of degeneration of acetabular articular cartilage was 0.34 ± 0.35 mm/year. The mean thickness of the acetabular articular cartilage is reported to be 1.0–3.6 mm [21, 22]. Hence, most cartilage should wear out approximately six years after surgery at which point abrasion of the acetabular subchondral bone would begin.

The dual articulation of the outer bearing and inner bearing is the key element of bipolar hemiarthroplasty. In our study, we found that outer bearing motion was predominant but that it had a tendency to decline during follow-up. We propose that the predominance of outer bearing motion is due to the difference between the frictional coefficients of the materials used for outer and inner bearings. The frictional coefficient between metal bipolar cup and acetabular cartilage is 0.0075–0.015, and between the metal head and the polyethylene liner of the inner bearing it is 0.06 [23]. These differences of frictional coefficient determine the joint motions, and the reduction in outer bearing motion could be explained by the increased friction due to degeneration of the articular cartilage. We detected a significantly higher rate of degeneration of acetabular articular cartilage and decline of the O/I ratio in the osteolysis group compared to the non-osteolysis group.

However, the nature of the joint is still debated. Vazquez-Vela et al. reported that joint motion occurred only at the outer bearing surface, contrary to theoretical expectations, and serious complications such as premature wear of the acetabular cartilage and protrusion of the acetabular cup could not be avoided [24]. However, according to Drinker and Murray, both outer and inner bearing motion occurs initially, but over time the inner bearing motion declines and eventually only the outer bearing motion remains [5]. On the other hand, Bochner et al. reported that joint motion occurred at both bearing surfaces [14]; whereas Mess et al. claimed that both joint motions occurred under non-weight-bearing conditions but only inner bearing motion under weight-bearing conditions [25]. Giliberty et al. found that dual motion occurred initially, but that the outer bearing motion declined as time went on, and finally only inner bearing motion remained [26].

From the above considerations, the incidence of osteolysis in bipolar hemiarthroplasty may be explained as follows. Initially, the outer bearing motion is higher than the inner bearing motion because of the difference in frictional coefficients. Then, over time, the motion of the outer bearing results in wear of the acetabular cartilage and the friction between metal and cartilage increases. This leads to a relative increase in inner bearing motion, and the motion between the metal head and polyethylene liner increases. As a result, polyethylene wear particles are generated and infiltrate into the surrounding bone,

resulting in osteolysis around the implant. This causes loss of mechanical strength and leads to protrusion of the bipolar cup. Our observations indicate that the above series of events progressed more rapidly in the osteolysis group than in the non-osteolysis group.

In conclusion, we could observe the high degeneration rate of acetabular cartilage and rapid decline of O/I ratio in the osteolysis group. Close observation is needed in cases of high degeneration rate of cartilage and rapid decline of O/I ratio due to possibility of osteolysis.

Conflict of interest The authors declare that they have no conflict of interest.

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