Why does outer joint motion predominate in bipolar hip prosthesis?

Experimental and clinical studies

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Background **Theoretically, the motion of a bipolar hip prosthesis is most likely to occur at the inner joint if the frictional coefficients are equal at both surfaces. However, many studies have suggested that most motion occurs at the outer joint.**

Material and methods **We performed an analysis of motion in a cadaveric bone model and in 50 patients during fluoroscopic examination, to determine how the motion is distributed between the two joints and what factors contribute to this distribution.**

Results **The motion distributions varied widely between the patients. However, there was a relative preponderance (63–90%) of outer motion in all directions of leg movement in addition to a persistent coexistence of motion at both joints in 44 of 50 patients. This preponderance of outer motion was the result of an early impingement of the acetabular cup and structural differences between the two joints.**

Interpretation **An adjustment of the positive eccentricity and a decrease in the frictional torque of the inner joint as a result of better lubrication and smoothness can be expected to improve the motion distribution, thus reducing the amount of acetabular erosion.**

The bipolar hip prosthesis is a combination of a cup arthroplasty and a unipolar prosthesis which provides two centers of articulation. The prosthetic head articulates with an outer polyethylene-lined metal cup (the inner joint), which in turn articulates with the acetabulum (the outer joint). Dual articulation combined with a positive eccentricity is expected to minimize the amount of acetabular wear with optimal component positioning (Krein and Chao 1984, Cornell et al. 1998, Chan and Shih 2000, Haidukewych et al. 2002).

Theoretically, the frictional torque ratio governing the occurrence of the inner and outer motion in a bipolar hip prosthesis is directly related to the product of the frictional coefficient ratio and the joint surface radius ratio (Krein and Chao 1984). Thus, motion is most likely to occur at the inner joint if the frictional coefficients are equal at both surfaces. In contrast, many studies have reported a predominance of motion at the outer joint unless the acetabulum is severely eroded (Bednar et al. 1988, Bochner et al. 1988, Rowe et al. 1994). Drinker and Murray (1979) reported that although some inner motion occurred in most implants, it was less than predicted. In a study of femoral neck fractures, Verberne (1983) noted minimal movement at the inner joint 3 months after surgery. Bednar et al. (1988) reported a 71% distribution of outer motion during weight bearing and a significant decrease in inner motion as a result of weight bearing. Phillips (1987) found that the prosthesis functioned largely as a unipolar device with movement occurring primarily at the outer joint in 75% of the fracture group. Wada et al. (1997) also reported that 80% of motion occurred at the outer joint during weight bearing and 83% of motion

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Table 1. Experimental design and the distribution of component motion between the inner and outer joints according to surface lubrication, cup angle, and acetabular reaming in the cadaveric acetabulum

Condition	Experimental design				Motion distribution			
	Application of lubricant [a]		Cup angle	Acetabular reaming [b]	Abduction		Return [c]	
	Outer joint	Inner joint			Initial (15°)	Full (35°)	Initial (15°)	Full (35°)
I	+	+	45°	None	Inner only	Inner only	Inner only	Inner only
II	+	+	20°	None	Inner only	Combined Inner (65%) Outer (35%)	Inner only	Inner only
III	+	–	45°	None	Outer only	Outer only	Outer only	Outer only
IV	–	–	45°	Yes	Inner only	Inner only	Inner only	Inner only

Condition I: Both joints were well lubricated and the acetabular cup angle was 45°.
Condition II: Both joints were well lubricated and the acetabular cup angle was 20°.
Condition III: Only outer joint was lubricated.
Condition IV: The acetabulum was reamed.
[a] Lubricant: 6-poise lubricant supplied by ISU Chemical Co., Korea
[b] Acetabulum was reamed about 2 to 3 mm in depth by an acetabular reamer of a THR instrument set.
[c] Return from full abduction to neutral.
+ : Lubricant was applied at each step of experiment.
– : Lubricant was not applied.

occurred when there was no weight bearing in abduction and adduction.

We performed an experimental and clinical analysis of component motion in bipolar hip prostheses to determine how the motion is distributed between the two joints and what factors contribute to this distribution.

Material and methods

Cadaveric bone study

We constructed an experimental model to examine the motion distribution of a bipolar hip prosthesis. The motion was investigated under four conditions, which differed in the extent of joint lubrication, acetabular erosion, and the initial angle of the acetabular cup (Table 1). These four conditions were designed to simulate different situations in the human body. In condition I, both joints were well lubricated and the acetabular cup angle was 45°. In condition II, both joints were well lubricated and the acetabular cup angle was 20°. In condition III, only the outer joint was lubricated. In condition IV, the acetabulum was eroded.

We used a fresh frozen cadaveric pelvis (acetabulum Ø 46 mm) supplied by New Mexico Donor Services, USA and an Osteo Bipolar Head prosthesis (outer head Ø 46 mm, inner head Ø 28 mm, cone size 12/14 mm). This implant is mechanically designed to have a positive eccentricity for self-centering. This implies that the center of rotation of the outer head is distal to that of the inner head. A valgus-producing moment of the outer head is generated on loading.

We used a 6-poise lubricant supplied by ISU Chemical Co., Korea to simulate joint lubricity. Acetabular erosion was simulated by acetabular reaming, approximately 2–3 mm in depth, using a THR acetabular reamer. The prosthesis was tested from the neutral position to full abduction and then back to the neutral position in the supine position. All experimental steps were videotaped and the stationary views were captured later and printed for analysis. To determine the degree of total motion, inner motion, and outer motion, we analyzed the stationary views using the method described by Drinker and Murray (1979) (Figure 1). The stationary views were measured separately by 3 of the authors and the averages were taken from the measured values.

Clinical study by fluoroscopy

Between January 1991 and December 2000, 272

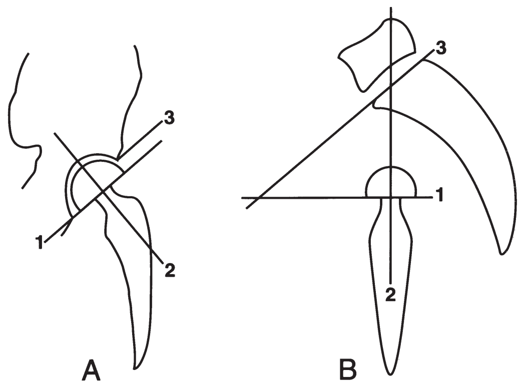


Figure 1. Measurements of relative motion at both the inner and outer joints in radiographs, according to Drinker and Murray (1979). Abduction-adduction motion was measured in the A-P view and flexion-extension in the lateral view (B): line 1 is parallel to the straight lateral edge of the outer cup, line 2 runs down the neck of the prosthesis, and line 3 is the acetabular index in the antero-posterior view and an extension of the upper margin of the sacrum in the lateral view. Angle 1-2 = inner motion, angle 1-3 = outer motion, and angle 2-3 = total motion.

Table 2. Details of the 50 patients who had fluoroscopic examination of their bipolar hip prosthesis for component motion

No. of patients (no. of hips)	50 (50)
Age in years at operation	
Mean (range)	57 (26–85)
Men / women	33 / 17
Preoperative diagnosis	
AVN [a]	25
Fracture [b]	25
Follow-up period (years)	
Mean (range)	7.3 (2–12)
Harris hip score	
Mean (range)	87 (52–100)
Radiographic acetabular erosion	
Yes	22
No	28
Prosthesis	
Swiss Osteo Bipolar Head	
Inner head diameter	28 mm
Positive eccentricity	yes
ROM of inner head with	
12/14 mm cone size	70°
14/16 mm cone size	65°
Cup position in supine	20°

[a] Avascular necrosis of the femoral head
[b] Femoral neck or inter-trochanteric fracture of the femur.

hip arthroplasties with bipolar prostheses were performed at our hospital. Among them, patients with unilateral replacement who could walk without support, and who had been operated more than 2 years previously, were included in this study. 50 volunteers (33 men) who had agreed to have fluoroscopic examination were studied (Table 2). Their mean age at the time of surgery was 52 (26–85) years. The preoperative diagnosis was hip fracture (n = 25) and avascular necrosis of the femoral head (n = 25). At the examination, their average Harris hip score was 87 (52–100) points. The average follow-up period was 7.3 (2–12) years. Patients received the same implant as used in the cadaver study. The range of possible motion in the inner joint was 70° with a 12/14 mm cone size, and 65° with a 14/16 mm cone size.

We studied movements of the prosthetic components in the 4 directions of leg movement including abduction, adduction, flexion, and extension by fluoroscopy with simultaneous videotaping. All patients were examined both supine and standing. The hip was kept in a neutral rotation during the procedure to eliminate variable rotation. Spot stationary views, 3 or 4 in each direction of motion, were taken from the video recording and printed for the measurements. As in the experimental study, the stationary views were analyzed to determine the motion using the method reported by Drinker and Murray (1979).

Statistics

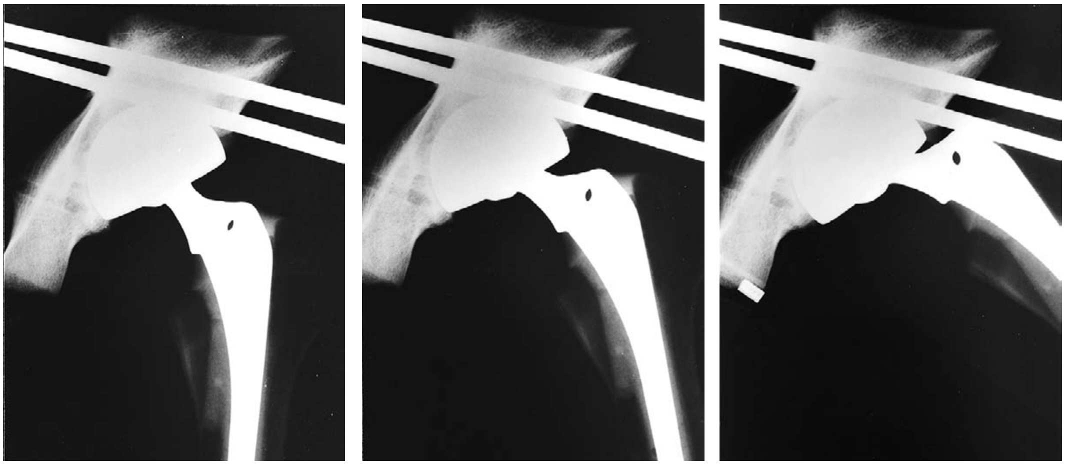
We used a paired t test for the variables showing a normal distribution. The influence of age at surgery (≤ 60, > 60 years of age), gender, preoperative diagnosis, time since operation (≤ 7, > 7 years), presence of acetabular erosion or not and Harris hip score at final follow-up (≤ 90, > 90) on the motion distribution between the 2 joints in abduction was studied in a multiple regression analysis. Statistical analysis was performed using the SPSS software package (SPSS for Windows Release 10.0; SPSS Inc., Chicago, Illinois). All analyses were set at the 95% confidence interval for significance.

Results

Cadaveric bone study

The relative distribution of the two joint motions for the 4 different conditions used to simulate the conditions in the human body was as follows: In condition I, motion occurred mainly at the inner

Figure 2. Radiographs showing the component motion in condition II.



A. Neutral position with conditions of lubrication in both joints, 20° acetabular cup angle and no acetabular erosion.

B. Initial abduction occurred only at the inner joint.

C. After impingement, most motion occurred at the outer joint.

Table 3. Relative distribution of motion between the inner and outer joints in 50 hips with the bipolar hip prosthesis, according to the direction of leg motion and weight bearing

	Abduction		Adduction		Flexion		Extension	
	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner
Supine								
Mean, degree	18	6	7	2	44	9	10	6
SD	9.0	6.0	4.7	4.3	24	14	13	8.7
Distribution, %	72	28	78	22	83	17	63	37
Standing								
Mean, degree	10	2	9	1	14	2	7	2
SD	5.4	2.9	4.5	3.8	7.3	5.4	7.9	4.9
Distribution, %	83	17	90	10	88	12	78	22
P-value								
Supine : Standing	0.03		0.09		0.5		0.01	

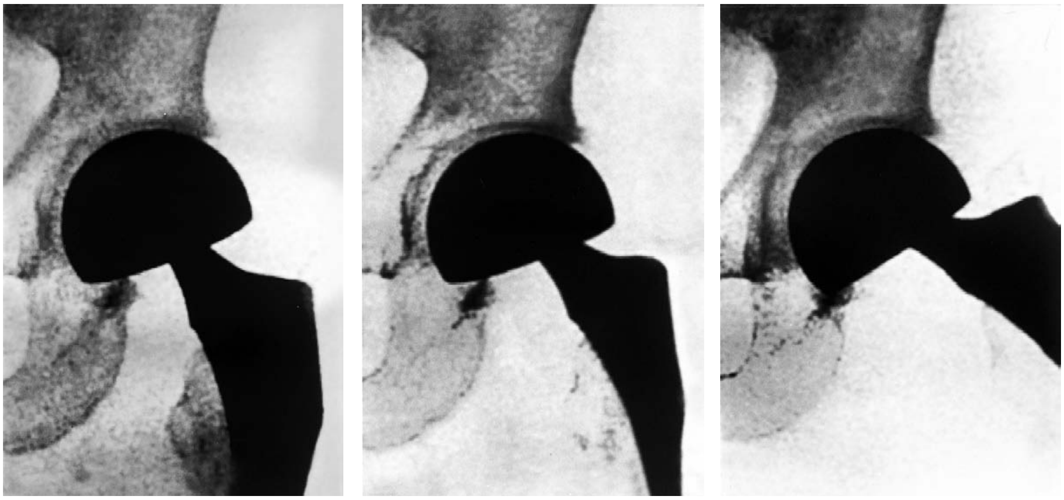
joint, as suggested by theory. However, if the acetabular cup angle was low, as in condition II, motion of the outer joint appeared in the terminal abduction following impingement of the femoral neck on the polyethylene liner (Figure 2). In condition III, motion occurred mainly at the outer joint. In condition IV, motion occurred mainly at the inner joint (Table 1).

Fluoroscopy study

The relative motion distribution of the two joints in the 4 directions of leg movement showed an overall predominance of motion in the outer joint (Table 3).

The motion distribution of the outer joint showed slight variation, depending on to the direction of leg motion and the amount of weight bearing (supine or standing). In abduction, the percentage distribution of outer motion was 72% in the supine position and 83% when standing ($p = 0.03$). In adduction, the percentage distribution of outer motion was 78% in the supine position and 90% when standing ($p = 0.09$). In flexion, the percentage distribution of outer motion was 83% in the supine position and

Figure 3. Fluoroscopic findings in one patient, showing impingement by the acetabular cup.

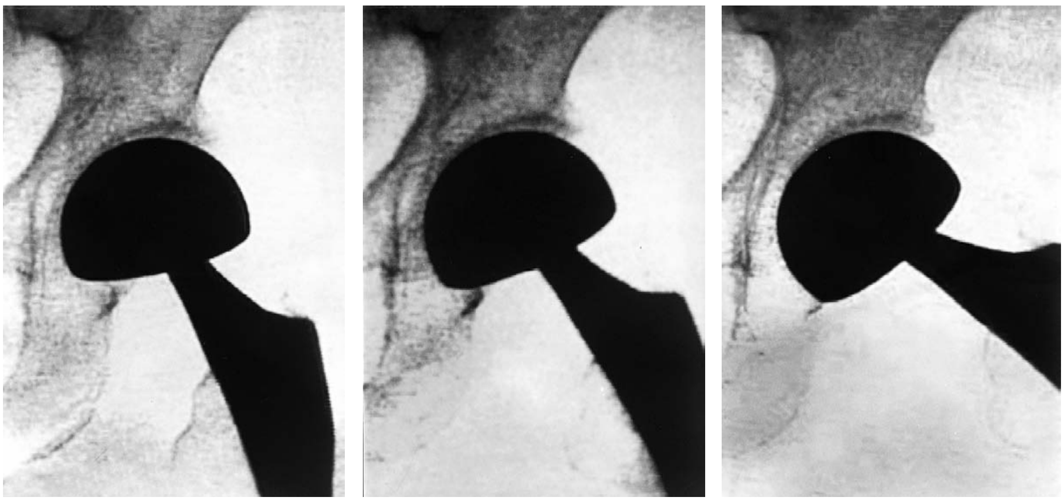


A. Neutral position with 15° acetabular cup angle.

B. Initial abduction occurred mostly at the inner joint (90%).

C. Outer motion appeared after impingement (outer 40%, inner 60%).

Figure 4. Fluoroscopic findings in a patient with outer motion predominating.



A. Neutral position on standing, with normal joint space.

B. Initial abduction occurred at the outer joint (100%).

C. Full abduction also occurred at the outer joint (100%).

88% when standing (p = 0.5). In extension, the corresponding figures were 63% in the supine position and 78% when standing (p = 0.01). In all directions of leg movement, the proportion of motion taken by the outer joint was increased when the patients were standing compared to when in the supine position.

According to the relative predominance of component motion in abduction, the 50 hips could be divided into 5 groups (Figures 3 and 4): 6 hips showing only outer motion, 29 hips showing combined motion of the two joints with a dominant contribution from the outer joint, 9 hips showing a similarly shared combined motion, 6 hips showing combined motion with a dominant contribution from the inner joint, and none with only inner motion (Table 4). These distributions showed that

Table 4. Predominance of component motion in abduction movement of the 50 patients. Values are no. of hips

Predominance of component motion	Abduction	Combined motion	Predominant inner motion	Predominant outer motion
Outer only	6		6	
Predominantly outer (> 60%)	29	29	29	
Similarly shared (50 ± 10%)	9	9		
Predominantly inner (> 60%)	6	6		6
Inner only	0			0
Total		44	35	6

the motion was shared between both the outer and inner joints in 88% of the hips and a predominance of outer joint motion (> 60%) in 70% of the hips.

The presence of acetabular erosion influenced the distribution of motion between the 2 joints. Among the 50 patients, acetabular erosion was observed in 22 hips. The percentage distribution of outer motion was 79% in the patients without acetabular erosion and 64% in the patients with acetabular erosion ($p = 0.02$). The other factors evaluated in the regression analysis did not reach significance ($p > 0.15$).

Discussion

Many factors can affect the motion distribution of the bipolar hip prosthesis in vivo, such as the condition of the acetabular cartilage (Phillips 1987, Bednar et al. 1988, Ito et al. 2000), the underlying joint disease (Phillips 1987, Bednar et al. 1988), time in situ (Drinker and Murray 1979, Verberne 1983, Phillips 1987, Bednar et al. 1988, Chen et al. 1989), the joint pressure (supine or standing) (Drinker and Murray 1979, Phillips 1987, Bednar et al. 1988, Bochner et al. 1988, Eiskijaer et al. 1989, Mess and Barmada 1990, Wada et al. 1997), the functional score of the hip (Bednar et al. 1988), the diameter of the inner head (22, 28, 32 mm) (Bednar et al. 1988), and the eccentricity of the inner head center (Phillips 1987). The extent to which the motions in the two prosthetic joints are preserved after a certain period of time has not been clearly defined. In addition, studies on the motion distribution of bipolar hip prostheses in vivo have reported conflicting results (Drinker and Murray 1979, Verberne 1983, Cabanela and Van-Demark 1984, Phillips 1987, Bednar et al. 1988, Bochner et al. 1988, Chen et al. 1989, Eiskjaer et al. 1989, Mess and Barmada 1990, Rowe et al. 1994, Wada et al. 1997).

Most clinical studies evaluating the motion distribution used plain radiography. We found a significant difference in the motion distribution between the plain and fluoroscopic radiographs in 21 of 50 patients. We believe that the fluoroscopic findings are more reliable because images are exposed during continuous motion.

We found a relative preponderance of outer motion and the continuous co-existence of motion in the two joints in most patients. The main question to be answered is why outer motion should predominate in a bipolar prosthesis. To our knowledge, the causative factors have not yet been clearly defined. According to our experimental and clinical results, two factors can be suggested to cause the preponderance of outer motion. Firstly, we found that outer motion was induced by an impingement of the femoral neck on the liner. As suggested in the theoretical motion analysis (Krein et al. 1984), almost all motion occurs at the inner joint when the two joints are well lubricated (condition I). However, our first experiment was conducted with the acetabular cup angle set at 45°. An initial angle of 45° could not be set in the current bipolar prosthesis, which has a positive eccentricity for self-centering. In the human body, a high degree of the valgus position of the acetabular cup, 10°–20°, is common. Thus, this angle can cause early impingement of the prosthetic neck on the liner during leg movement. This impingement eventually induces motion of the outer cup. We observed this phenomenon in our experiments and fluoroscopic studies. Secondly, structural differences between the inner and outer joint also caused a preponderance of outer joint motion. The inner joint is a mechanical joint constructed between the polyethylene liner and the metal or ceramic head. These are round and congruent. Subsequently, when weight is applied, all the synovial fluid will be pressed out to the synovial pocket and the frictional torque of the inner joint becomes greater than that of the outer joint (Drinker and Murray 1979). In contrast, the outer joint, which consists of a horseshoe-shaped acetabulum and a round acetabular cup, is not perfectly congruent and can contain some synovial fluid. Thus, the outer joint is more lubricated than the inner joint, and motion is more likely to occur at the outer joint, as demonstrated in condition III.

We also found that several factors may reduce motion in the outer joint. As shown in condition IV, the conditions that increase the frictional torque of the outer joint cause a decrease in motion. Clinical examples of this condition are acetabular erosion caused by an artificial head and avascular necrosis of the femoral head.

One weakness of our study is that comparatively few patients were studied and that they were heterogenous concerning age, gender, preoperative diagnosis, and postoperative follow-up period.

Our clinical study has clarified two issues regarding the motion distribution of the bipolar components. Firstly, although the motion distribution varied between the patients, the persistent coexistence of the motion of the two joints was found in most of the patients. Secondly, we found a predominance of outer motion in all directions of leg movement.

No competing interests declared.

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