

# Reduction of polyethylene in a congruent meniscal knee prosthesis

## Experimental and clinical studies

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*Polyethylene wear was assessed in the Rotaglide congruent meniscal bearing total knee prosthesis and a partial congruent total knee prosthesis with fixed bearing polyethylene tibial platform and a posterior stabilizer mechanism. A special wear test rig was used to test the 2 prostheses under compression load of 2960 N/mm<sup>2</sup> (about 4 times the average body weight) and continuous 0°-70° flexion-extension motion at the rate of 1 cycle per second. The most remarkable finding was the lack of measurable wear on the Rotaglide meniscal bearing up to 3.5 million cycles, while the other prosthesis began to show wear from the first million cycles and progressed to 0.38*

*mm at about 3.5 million cycles. At 11 million cycles (about 20 years of life), the Rotaglide showed penetration wear of 0.35 mm compared to 2.1 mm in the other prosthesis. In 7 meniscal bearings, retrieved either at postmortem (2) or at reoperation (5), no measurable penetration wear was observed after 3 years of implantation. Only 1 prosthesis obtained 5 years after implantation showed 0.23 mm penetration wear or about 0.05 mm per year. These findings strongly suggest that the use of congruent meniscal bearing prosthesis can reduce the polyethylene wear in total knee replacement.*

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The longevity of a knee prosthesis is governed by two factors, infection and mechanical failure. Mechanical failure depends on wear, fixation and kinematics (Vince 1995). While modern prostheses have solved the problem of kinematics and fixation, wear has become a central concern in new designs. Since its introduction as a suitable material for a low friction arthroplasty, polyethylene has been increasingly used in the production of most artificial joints, including knee prostheses. However, the wear of the ultra high molecular weight polyethylene (UHMWPE), limits the life of total joint replacement prostheses. Characteristic of polyethylene wear is the loss of particles which have a biologic effect on the prosthesis-bone interface (Amstutz et al. 1992) and an altered mechanical behavior of the component.

Factors which contribute to wear include the mechanical characteristics of the materials from which the prosthetic component is made, the smoothness-roughness of the articulating surfaces, speed of movement, the patient's weight and the size of the contact surface area. The mechanical behavior depends on manufacturing techniques, means of processing, sterilization techniques, storage time, thickness of the

polyethylene and loading conditions (Ayers 1996, Heim et al. 1996)

The condylar knee prosthesis employs articulation between a metal femoral component and an UHMWPE tibial component. As a result, wear debris is mostly polyethylene particles, while metal, cement and bone debris are far less. The effect of these particles on the artificial joint is directly related to osteolysis, which can appear around the prosthesis even one year after its implantation (Colliza et al. 1995, Eng et al. 1992, Gomez and Barena 1996).

## Material and methods

A condylar prosthesis was designed, consisting of a metal femoral component, a metal tibial tray and a mobile polyethylene platform in between (Polyzoides et al. 1996)(Figure 1). The femoral surface consists of two 24 mm radial, spherical surfaces lying with their centers 44 mm apart in the flexion axis of the knee. Each condyle, therefore, forms a surface which has exactly the same radii in the oblique and the frontal plane and is fully congruent with two dishes of the



Figure 1. The prosthesis as it was initially designed. The metal femoral component is congruent to the mobile polyethylene platform which sits on the tibial tray. The polyethylene platform moves 5 mm anteriorly-posteriorly, and rotates 25° internally-externally.

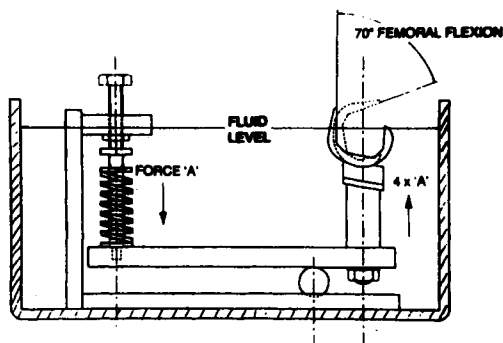


Figure 2. The rig which was designed to measure the wear of the Rotaglide prosthesis.

upper surface of the mobile polyethylene platform, from full extension to 110° flexion. During extension-flexion the platform can move forwards and backwards for 5 mm, while simultaneously it is possible to rotate internally and externally for 25°, thus producing rotation and gliding which simulates the natural knee movements. Two posts on the upper surface of the metal tibial tray control rotation and gliding, preventing dislocation of the mobile platform.

Wear in the new prosthesis was assessed in a 1) contact surface area study with pressure sensitive films, 2) joint simulator to measure the wear of the polyethylene and a wear test of the mobile polyethylene platform on the metal tibial component, and 3) clinical studies on retrieved polyethylene meniscal bearings (platforms) and radiographic examination of the congruent prosthesis with a follow-up of 6 years.

The contact surface area study was carried out at Mount Sinai Medical Centre, Ohio, using medium and ultra super-low scale pressure sensitive films to measure the articulating surface stresses and contact area of 12 popular knee prostheses

Polyethylene wear was evaluated experimentally using a knee joint simulator. A simplified wear rig was designed to measure the wear of the polyethylene in the Rotaglide prostheses (Figure 2). A popular partially congruent posterior stabilizer fixed bearing condylar prostheses was chosen to be tested under the same loading conditions. 4 times the body weight was applied and the movement was set from full extension to 70° of flexion and adjusted to run approximately at 1 cycle per second. Both prostheses were tested fully immersed in saline at room temperature. The thickness of the polyethylene was 9 mm in both prostheses. The results were recorded at every million cycles (Gremore and Tuke 1995).

Wear tests of the mobile polyethylene platform on the metal tibial component were performed in order to assess the amount of any wear occurring as the result of impaction of the UHMWPE meniscal bearing on the anterior and posterior tibial posts of the metal tibial tray which are placed to prevent dislocation of the platform and to control gliding and rotation. A medium size metal tibial component articulated with a 9.5 mm thick polyethylene meniscal bearing (platform) was put on a test machine applied 20% of the static normal weight. Anteroposterior force was applied by loading 150 N on the meniscus against each post. The test was conducted in saline at room temperature. Results were recorded at every one million cycles.

Clinical studies for wear measurements on retrieved meniscal bearing were performed on 2 meniscal bearings retrieved postmortem, 3 and 5 years, postoperatively, and 5 were obtained at reoperation for patellar problems (at 2 years (n=4) and 3 years (n=1) postoperatively). The polyethylene meniscal bearing were measured for thickness and tested for penetration wear using a dial gauge. They were mapped for contact area on the upper surface which articulates with the femoral component.

## Results

The average contact surface area of the 12 popular prostheses was 235 (131–671) mm<sup>2</sup> in extension, 163 (132–242) mm<sup>2</sup> at 60° of flexion, and 151 (122–189) mm<sup>2</sup> at 90° of flexion (Table 1). In comparison, the Rotaglide exhibited 645 mm<sup>2</sup> in full extension, 1053 mm<sup>2</sup> at 60° in flexion and 709 mm<sup>2</sup> in 90° of flexion. According to the safety guidelines, the UHMWPE

tibial component should not be exposed to sliding loading of more than 10–15 N/mm<sup>2</sup> (Hoechst Manual 1977, 1989). Walking produces forces at the femorotibial articulation which are at least 4 times the body weight. With an average BW of 74 kg, forces are about 3000 N, indicating that the necessary contact surface area should be 300 mm<sup>2</sup>. Thus, the contact surface area of the 12 contemporary knee prostheses is 54% of the manufacturers recommendation in 60° of flexion, and is even less (50%) in 90° of flexion.

At 3 million cycles the fixed bearing, partial congruent condylar prosthesis showed a penetration wear of 0.38 mm in the lateral compartment and 0.43 mm in the medial one. No penetration wear was seen in the congruent meniscal bearing Rotaglide Knee prostheses. At 5 million cycles which corresponds to 10 years of life, the partially congruent fixed bearing condylar prosthesis showed the effect of wear to be more pronounced. The initial rectangular contact area of 2 mm (10 mm on each compartment was enlarged and deepened, by a penetration wear of 0.85 mm on either side. Polyethylene particles were floating in the saline reservoir. At 11 million cycles the penetration wear for the congruent meniscal bearing prosthesis was 0.35 mm compared to 2.1 mm (6 times more wear) with the partially congruent fixed bearing prosthesis (Table 2).

The anteroposterior dimension of the meniscal bearing was reduced by 0.1 mm at 3 million cycles. The undersurface of the bearing showed only a little burnishing, but no measurable wear. The anterior post caused a small indentation in the polyethylene associated with creep rather than wear, while the posterior post caused no discernible damage. When static load was increased to 3 times the body weight, the anterior post caused a small dent of 0.5 mm, but no polyethylene failure.

Only the meniscal bearing which was received postmortem at 5 years postoperatively showed 0.23 mm of penetration wear in both condylar surfaces; a yearly penetration wear rate of 0.046 mm. The other postmortem specimen and the 5 retrieved at reoperation showed no measurable penetration wear, pitting or delamination.

AP and lateral radiographs with the patient weight bearing of 33 knees (30 patients) with 6 years follow-up and another 64 knees (60 patients) with 5 years follow-up were examined for radiolucent lines in zones adjacent to the cement, for osteolysis, polyethylene thickness, and any asymmetry (Figure 3). Only 6 of 97 knees (6%) showed a nonprogressive line of 1 mm or less under the tibial component. 2 radiolucent lines at the posterior condyles were noted on the femoral side; both lines appeared immediately postoperatively

**Table 1. Contact areas**

Product name		Contact area (mm <sup>2</sup> )		
		0°	60°	90°
Advantin	Total Condylar	193	162	147
	LSI	286	166	152
AMK	Standard	172	148	136
Axiom	Standard	177	134	133
CKS	Primary	149	153	157
Duracon	Standard	162	163	160
Genesis	Standard	254	161	149
LCS	Meniscal bearing	671	242	189
MG II	Flat	153	136	134
	A/P Lipped	151	132	129
Natural	Congruent	195	202	147
	Ultra Congruent	258	203	160
Omnifit	Series I	156	135	134
	Series II	190	138	134
Performance	PCL Substituting	131	138	145
PFC	Curved	225	180	171

**Table 2. Penetration wear measured in a fixed and Rotaglide prosthesis**

Cycles x10 <sup>6</sup>	Fixed bearing		Rotaglide	
	M	L	M	L
1.03	0.23	0.18	No change	No change
2.20	0.28	0.28	No change	No change
3.30	0.38	0.43	No change	No change
4.15	0.43	0.43	0.1	0.1
5.80	0.95	0.94	0.15	0.10
11.00	2.1	2.1	0.35	0.35

without any subsequent deterioration. Osteolysis was not observed in any knee.

A slight joint space asymmetry was observed in 2 knees, but this was noted at 6 months postoperatively and was due to the tibio-femoral angle (one in varus and the other in 15° valgus). This asymmetry did not change, and there was no deterioration in the comparative measurements for thickness at 1 and 5 years and no asymmetry in the remaining knees.

## Discussion

Wear of the polyethylene with subsequently osteolysis and loosening of the condylar knee prosthesis has been of concern and has been considered as a limiting factor in the survivorship of total joint replacements (Wright and Bartel 1986, Landy and Walker 1988, Eng et al. 1992, Blunn et al. 1991, Nolan and Backnill 1992, Collier et al. 1991, Wright et al. 1992). The results of the present study show that under the same loading environment, the fixed bearing with partial tibiofemoral congruency exhibits 6 times more pene-

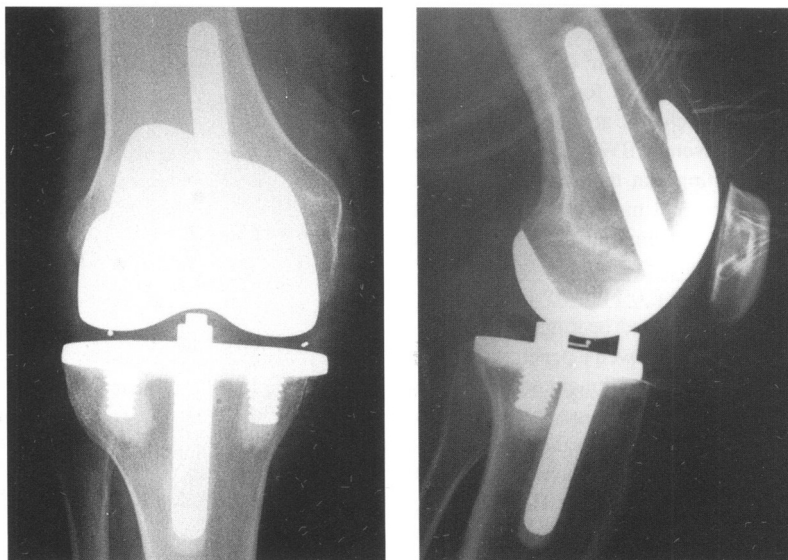


Figure 3. Anteroposterior (left) and lateral (right) radiographs of the prosthesis which were used to study radiolucency which was present in only 6% of 97 operated knees with a minimum follow-up of 5 years.

tration wear than the mobile bearing of the Rotaglide congruent meniscal knee prosthesis. The size of the contact surface area was found to lay a vital role in the reduction of the polyethylene wear in the condylar knee prosthesis (Argenson and O'Connor 1992, Plante-Bordeneuve and Freeman 1993). In this regard, area contact versus line or point contact is able to reduce the contact pressure and, in turn, the wear of the polyethylene. In addition, positional changes of the contact area occur during gait in minimal constraint incongruent or partial congruent knee prostheses which alter the contact pattern and surface stresses (Heim et al. 1996, Blunn. 1991).

The large contact surface area of the Rotaglide meniscal knee prosthesis, as measured by Heim and Postak (1996), is the result of congruency. The combination of a mobile platform and femorotibial congruency gives several advantages to the Rotaglide meniscal bearing prosthesis since congruency eliminates translation of the contact surface area and helps the reduction of wear. Also, the mobile meniscal bearing gives the possibility of a more physiological movement, avoiding anteroposterior translation of the femoral component on the tibial polyethylene surface, by the anteroposterior gliding of the femoral metal component in articulation with the congruent surfaces of the platform on the tibial tray. This reduces polyethylene wear, improves kinematics and helps in bone fixation by reducing the stress at the interface.

Our studies demonstrate that even under extreme experimental conditions, the new prosthesis design

reduced the amount of polyethylene wear. Similarly, measurements of the wear in the retrieved bearings from either postmortem or reoperation, confirmed that the penetration rate was 0.046 mm per year. These findings were compatible with previous reports (Argenson and O'Connor 1992, Plante-Bordeneuve and Freeman 1993). In contrast, the Charnley hip prostheses with a small contact surface area of 380 mm<sup>2</sup> was found to have a penetration rate of 0.19 mm<sup>2</sup> per year (Wroblewski 1985, Livermor et al. 1990) which is considerably greater than that measured for the congruent knee prosthesis.

Although component wear is an unavoidable consequence in total hip replacement, the results of the present report indicate that optimization of the prosthesis design should seek to maximize contact area, while minimizing the post yield region. Moreover, the findings suggest that congruency provides these advantages.

## References

- Amstutz HC, Campbell P, Kossovsky N, Clarke JC. Mechanism and clinical significance of wear debris-induced osteolysis. *Clin Orthop* 1992; 276: 7-18.
- Argenson JN, O'Connor JJ. Polyethylene wear in meniscal knee replacement *J Bone Joint Surg (Br)* 1992; 74: 228-32.
- Ayers DC. Complications following total knee Arthroplasty. Instructional Course Lecture 168 AAOS Atlanta Georgia 1996.

- Blunn GW, Walker PS, Joshi A. The dominance of cyclic sliding in producing wear in total knee replacement. *Clin Orthop* 1991; 273: 253-60.
- Charnley J. *Low friction Arthroplasty: Theory and Practice*. Springer Verlag, Berlin. 1979.
- Collier JR, Mayor MB, McNamara J. Analysis of the failure of 122 polyethylene inserts from uncemented tibial knee components *Clin Orthop* 1991; 273: 232-42.
- Colliza WA, Insall JN, Scuderi GR. The Posterior Stabilized Total Knee Prosthesis. Assessment of polyethylene damage and osteolysis after a ten-year - minimum follow up. *J Bone Joint Surg (Am)* 1995; 77: 1713 -18.
- Eng GA, Dwyer KA, Hanes CK. Polyethylene wear of metal-backed tibial components in total and unicompartmental knee prostheses *J Bone Joint Surg (Br)* 1992; 74: 9-17.
- Heim CS, Postak P, Greenwald AS. Factors influencing the longevity of UHMWPE tibial components. *Instructional Course Lectures* 1996; 45: 303-12.
- Heim CS, Postak PD. Tibial-femoral surface stress distributions and contact areas of the Corin Rotaglide Total Knee system: A pre-market release evaluation. *Orthopaedic Research Laboratories of the Mt. Sinai Medical Center, Cleveland Ohio USA* 1996.
- Hoechst Technical Manual Hostalen GUR. September 1977, 1989.
- Landy MM, Walker PS. Wear of UHMWPE components of 90 retrieved knee prostheses *J Arthroplasty* 1988; 3 (Suppl): 575-85.
- Nolan JF, Buckill TM. Aggressive granulomatosis from polyethylene failure in an uncemented knee replacement. *J Bone Joint Surg (Br)* 1992; 74: 23-4.
- Plante-Bordeneuve P, Freeman MAR. Tibial high density polyethylene wear in conforming tibiofemoral prostheses *J Bone Joint Surg (Br)* 1993; 75: 630-6.
- Polyzoides AJ, Dendrinis GK, Tsakonas AC. The Rotaglide Total Knee Arthroplasty. Prosthesis design and early results. *J Arthroplasty* 1996; 11: 453-9.
- Vince KG. Principles of Condylar Knee Arthroplasty: Issues Evolving. *AAOS Instructional Course Lectures*. 1993; 42: 315 -24.
- Wright TM, Bartel DL. The problem of surface damage in polyethylene total knee components. *Clin Orthop* 1986; 205: 67-74.
- Wright TM, Rinnac CM, Stulberg SD, Mintz L, Tsao AK, Klein RW, McCrae C. Wear of polyethylene in total joint replacements: observations from retrieved PCA knee implants. *Clin Orthop* 1992; 276: 126-34.
- Wroblewski BM. Direction and rate of socket wear in Charnley low-friction arthroplasty *J Bone Joint Surg (Br)* 1985; 67: 757-61.