WEAR PATTERN OF RETRIEVED PATELLAR IMPLANTS

O. SCHWARTZ, J. AUNALLAH, M. LEVITIN, D. G. MENDES

The so-called "papillon" pattern of polyethylene wear of 17 patellar components from 5 Kinematic and 12 Total Condylar prostheses, retrieved after an average of 80 months *in situ*, was studied. The primary diagnosis was osteoarthritis in all cases.

Four modes of damage were observed : polishing in 13 cases, delamination in 12, cold flow in 6 and scratching in 3. The median total area of polyethylene damage was 76.5% for polishing, 70.6% for delamination, 35.3% for cold flow and 17.6% for scratching.

The importance of the conformity of the Kinematic patellar component in order to decrease contact stresses was confirmed. The average contact stresses on the nonconforming Total Condylar patellar component (12.9 kgf/mm^2), were significantly higher ($p < 0.002$) than the average contact stresses on the conforming Kinematic patellar component (2.9 kgf/mm^2).

The area of wear was smaller for the nonconforming Total Condylar (357.2 mm^2) than for the conforming Kinematic patella (439.2 mm^2). This difference, however, is not statistically significant.

The average weight of the patients with a Kinematic Knee (74.5 kg) was higher than that of patients with a Total Condylar knee (66 kg), but the difference was not significant.

The high incidence of significant wear of the patellar components indicates that a basic deficiency is present in the design of patellar implants, and calls for the improvement of two mechanical features : adequate thickness of the polyethylene implant and conforming articulating surfaces.

Keywords : patellar implant ; wear ; polyethylene.
Mots-clés : implant rotulien ; usure ; polyéthylène.

INTRODUCTION

Considerable controversy exists regarding the necessity for patellar resurfacing in total knee arthroplasty (2, 5, 9, 10, 16-19, 21, 25, 26, 28, 30, 36, 40-42, 49, 51), since complications such as wear, impingement, instability, loosening and fracture have been documented as causes for failure of the patellar implant in about 50% of failed total knee arthroplasties (4, 8, 12, 20, 24, 27, 30, 34).

The contact between metal and polyethylene components articulating with each other results in a complex stress distribution pattern within the polyethylene ; stresses are higher for nonconforming than for conforming implants.

Quantitative measurements of polyethylene surface damage in retrieved total knee joint components have shown that the severity of damage to the surface correlates with the stresses applied, the patient's weight and the length of time that the component was in use. Not unexpectedly, the severity of surface damage is inversely correlated with the thickness of the polyethylene (3, 13, 22, 46, 53). The geometry of the trochlear grove is also of significance (33).

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It is clear that UHMWPE wear debris constitutes the main cause for long term failure (50) ; the lytic granulomatous response to the huge number of these minute particles has been widely described (7, 31, 38, 44, 46, 50). Therefore. it is our responsibility to reduce wear as much as possible in order to prolong the longevity of the implant. Patellar resurfacing has been recommended (40) in patients with the following criteria : when dominant anterior knee pain is present, when height and weight are average or more, when there is imaging evidence of anterior compartment disease and in cases with inflammatory and crystal deposition diseases. Following knee arthroplasty without patellar resurfacing, more patients had difficulties climbing stairs and complained of anterior knee pain (47).

Indeed, patellar resurfacing has more often than not been accepted as an important part of total knee arthroplasty, if a consistent result is to be expected (33).

In this paper we shall report on our study of the modes of wear of 17 retrieved patellar implants and point to two basic mechanical faults in their design : their inadequate thickness and their lack of conformity.

MATERIAL AND METHODS

We studied the wear patterm of 17 polyethylene [UHMWPE] patellar components retrieved following an average use of 80 months.

The primary diagnosis was osteoarthritis in all cases. There were two designs : 5 Kinematic, and 12 Total Condylar patellar components (both from Howmedica, Rutherford, USA). The implants were retrieved from 6 men and 11 women with an average age of 64 years at the time of arthroplasty. Their average height was 168 cm and average weight was 68.5 kg.

In all cases, the revision was performed for mechanical loosening of one or several components. The patellar components were examined for evidence of gross deformation. Using light microscopy, the articulating surface of each patellar component was analysed for six modes of damage :

1. Surface deformation, with “re-shaping” of the polyethylene, presumably due to cold flow.
2. Pitting, shallow and irregular voids.
3. Scratching.
4. Polishing.
5. Abrasion, areas where the polyethylene had a shredded or tufted appearance.
6. Delamination, where a layer or sheet of polyethylene had separated or peeled away from the bulk of the component.

Our grading system followed that described by Wright *et al.* (table I).

To locate the surface damage, the patellar component was divided into four sections (fig. 1).

The contact stresses between the patellar and femoral components were calculated in relation to the areas of wear. Volumetric wear could not be accurately established.

Table I. — Scoring system for patellar wear grid fixture

Polishing	
1.1.	Very little wear of machine lines
1.2.	Medium wear of lines
1.3.	No lines, completely polished
Cold flow	
2.1	< 1/3 of box covered.
2.2	1/3 to 2/3 of box full
2.3	2/3 to all of box full
Scratching	
3.1	Hardly visible
3.2	Definite scratch
3.3	Deep scratch
Pitting	
4.1	< 1/3 of box full
4.2	1/3 to 2/3 of box full
4.3	2/3 to all of box full
Abrasion	
5.1	< 1/3 of box full
5.2	1/3 to 2/3 of box full
5.3	2/3 to all of box full
Delamination	
6.1	< 1/3 of box full
6.2	1/3 to 2/3 of box full
6.3	2/3 to all of box full

Scoring system for grading wear of the UHMWPE patellar component surface. Each patella was examined through a grid made up of 2 × 2 mm squares and each square was rated using this scoring system.

Table II. — Wear score for all patellar components

Case	Prosth. Type	Time To Failure (Cycles)	Contact Stress* kgf/mm^2	Polish-ing	Cold Flow	Scrat-ching –	Pit-ting	Abra-sion	Dela-mina-tion	Total wear area mm^2
1	Kinem	4.41E6	2.9	–	–	–	–	–	6.3	444
2	TC	4.32E6	12.3	1.3	–	–	–	–	6.2	417
3	TC	2.16E6	12.3	1.2	–	–	–	–	6.1	180
4	TC	2.1E6	13.28	1.2	–	–	–	–	6.3	637
5	Kinem	9.72E6	2.95	–	–	–	–	–	6.3	679
6	Kinem	8.10E6	2.85	–	–	–	–	–	6.3	458
7	TC	12.96E6	12.3	–	–	–	–	–	6.1	115
8	Kinem	3.96E6	2.79	3.2	–	3.2	–	–	6.3	582
9	TC	5.40E6	12.44	1.3	2.3	–	–	–	6.3	535
10	TC	4.86E6	12.77	1.3	–	–	–	–	–	584
11	TC	1.44E6	13.51	1.2	–	3.2	–	–	–	300
12	Kinem	0.45E6	3.01	1.1	–	–	–	–	6.2	33
13	TC	Unknown	15.2	1.3	2.1	–	–	–	–	222
14	TC	Unknown	13.4	1.3	2.1	–	–	–	6.2	401
15	TC	Unknown	13.46	1.3	2.1	3.3	–	–	–	191
16	TC	Unknown	12.44	1.3	2.1	–	–	–	–	216
17	TC	Unknown	11.78	1.2	2.1 -	–	–	–	6.2	488

* The maximum contact stress for level walking [10- 12° knee bending].
** According to scoring system [1].

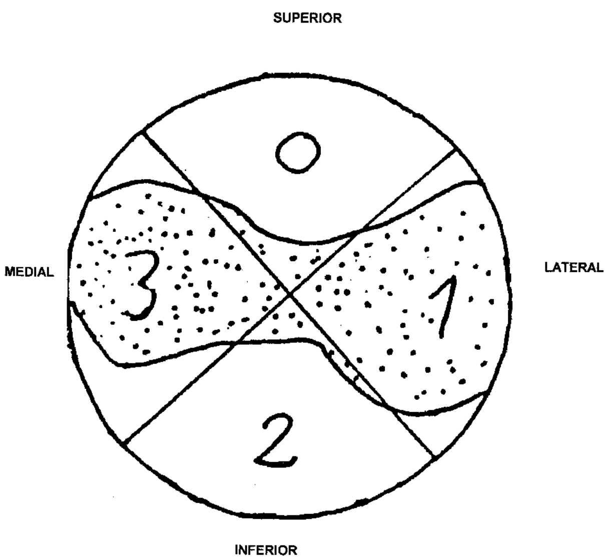

Fig. 1. — Location of wear damage to the patellar implant divided into our surface sections ("Papillon" pattern).

RESULTS

Analysis of the articulating surfaces of the 17 polyethylene patellar components disclosed severe changes, reflecting four modes of damage.

Table III. — Frequency of wear modes for all patellar components

Failure mode	17 Patellar components
Polishing	76.5%
Delamination	70.6%
Cold flow	35.3%
Scratching	17.6%
Pitting	0%
Abrasion	0%

Delamination of the surface as noted in 12 components was the most severe mode, polishing (burnishing) in 13 was the most frequent. Cold flow deformation was observed in six components and scratching of the polyethylene surface in three.

The grading system using the patellar wear grid fixture (50) is shown in table I. The contact stresses and total area of wear measured for each patellar component are shown in table II. The pattern of damage that we called "papillon" (bow tie) consisted of areas of wear that were more extensive at the periphery and joined at the centre (fig. 1).

For the conforming Kinematic implants, the average contact stress was relatively low at

Table IV. — Wear score for the Kinematic patellar component

Case	Prosth. Type	Time To Failure (Cycles)	Contact Stress* kgf/mm²	Polish-ing	Cold Flow	Scrat-ching –	Pit-ting	Abra-sion	Dela-mina-tion	Total wear area mm²
1	Kinem	4.41E6	2.96	–	–	–	–	–	6.3	444
5	Kinem	9.72E6	2.95	–	–	–	–	–	63	679
6	Kinem	8.10E6	2.85	–	–	–	–	–	6.3	458
8	Kinem.	3.96E6	2.79	–	–	3.2	–	–	6.3	582
12	Kinem	0.45E6	3.01	1.1	–	–	–	-	–	33

Average time to failure 5.38E6 Average total wear area 439.2 mm²

* The maximum contact stress for level walking [10-12° knee flexion].
** According to scoring system [1].

Table V. — Wear score of the Total Condylar patellar component

Case	Prosth. Type	Time To Failure (Cycles)	Contact Stress* kgf/mm²	Polish-ing	Cold Flow	Scrat-ching –	Pit-ting	Abra-sion	Dela-mina-tion	Total wear area mm²
2	TC	4.32E6	12.3	1.3	–	–	–	–	6.2	417
3	TC	2.16E6	12.3	1.2	–	–	–	–	6.1	180
4	TC	2.16E6	13.28	1.2	–	–	–	–	6.3	637
7	TC	12.96E6	12.3	–	–	–	–	–	6.1	115
9	TC	5.40E6	12.44	1.3	2.3	–	–	–	6.3	535
10	IC	4.86E6	12.77	1.3–	–	–	–	–	–	584
11	TC	1.44E6	13.51	1.2–	–	3.2–	–	–	–	300
13	TC	Unknown	15.2	1.3	2.1	–	–	–	–	222
14	TC	Unknown	13.4	1.3	2.1	–	–	–	6.2	401
15	TC	Unknown	13.46	1.3	2.1	3.3	–	–	–	191
16	TC	Unknown	12.44-	1.3	2.1	–	–	–	-	216
17	TC	Unknown	11.78	1.2	2.1	–	–	–	6.2	488

Average time to failure 4.76E6 Average total wear area 357.2

* The maximum contact stress for level walking [10-12° knee bending].
** According to scoring system [1].

2.9 kgf/mm², and the average wear area was 439.2 mm² (table IV). For the non-conforming Total Condylar implants, the average contact stress was significantly (p < 0,002) higher (12.9 kgf/mm²) and the average wear area was smaller (357.2 mm²), though the differences were not significant (table V). The two groups were similar in regard to the polyethylene thickness of the components : the center was about 8 mm thick with gradual thinning down to 2.5 mm at the periphery. The most severe damage by delamination was observed when time in use of the implant was longer - an average of 90 months as compared to 80 months *in situ* for the entire group. There was a difference (though not significant) in the average weight, which was higher in the Kinematic group (74.5 kg) than in the Total Condylar group (66 kg).

DISCUSSION

The patellar component in total knee arthroplasty is subject to postoperative mechanical complications such as polyethylene breakage and wear. In a 5 to 8 years follow-up study, Wright *et al.* (54), reported that the incidence of loosening of all-polyethylene dome-shaped patellas was higher than that of tibial and femoral components combined.

Numerous studies have pinpointed various factors influencing the extent of wear of the tibial (and patellar) polyethylene components (11, 14, 15). These include knee alignment, polyethylene thickness, surface geometry, quality of the polyethylene, manufacturing processes such as heat treatment of the articular surfaces and gamma irradiation in air used for sterilizing the components (1, 29, 37).

Surgical technique and choice of tibial and femoral components obviously influence both the extent and mode of wear. The Kinematic prosthesis allows for a femorotibial gliding motion in the anteroposterior plane and in rotation during flexion. The motion is influenced by tightness of the posterior cruciate ligament. This is in contrast to the Total Condylar prosthesis, for which the posterior cruciate ligament is excised, and AP translation and rotation are limited.

Preoperative ligament imbalance due to varus or valgus deformity is correlated with either prosthesis at the time of arthroplasty, to provide stability and to allow for an optimal range of motion.

However, forces related to residual soft tissue imbalance may cause high loads in tight knees or excessive mediolateral and rotatory motion in a lax knee, in either case leading to increased wear, which can cause implant failure (6, 23, 54).

It should be noted that patellar tracking is influenced by multiple factors including those mentioned above and other factors such as the positioning of the femoral and tibial components, particularly their rotational alignment, the centering or excentering of the patellar component, the design of the patellofemoral articulation and the balance and control of the patella's six degrees of freedom by the quadriceps mechanism. In addition, static alignment of the patella, even if achieved at surgery, may not correlate with the dynamic functional pull of the quadriceps when in active use. In our study, the data relating to patellar alignment was insufficient and hence we were not able to draw any conclusions in regard to these points.

Theoretically, providing conformity of the contact areas of the patellofemoral articulation should increase the life expectancy of the patellar implant. A conforming implant lasted 20 times as many cycles *in vitro* as a dome-shaped implant, before equivalent amounts of volume of wear were noted in the contact area (23).

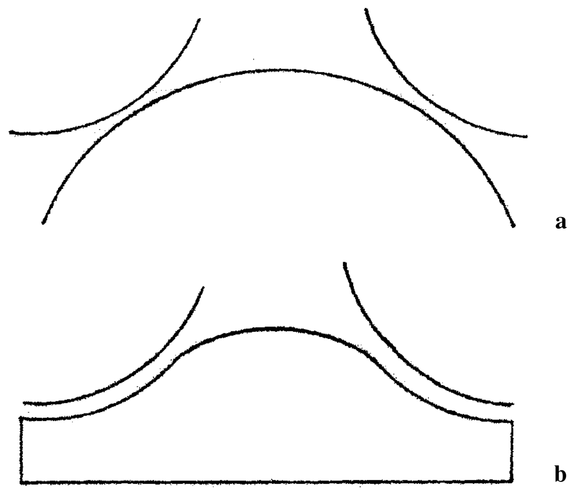

Fig. 2. — Patellofemoral profiles. (a) the nonconforming dome shape design producing points of contact in flexion and (b) the conforming design producing lines of contact in flexion.

In the Total Condylar patellar component the polyethylene articular surface is dome - shaped, and does not conform to the shape of the femoral condyles (fig. 2). The Kinematic patellar component conforms more closely to the articular surfaces of the femoral component. The importance of conformity in increasing contact area and decreasing contact stresses has been well established (3). Indeed, in our study, the dome-shaped nonconforming Total Condylar patellar component was subjected to an average contact stress of 12.9 kgf/mm^2, which was significantly higher ($p < 0.002$) than the average contact stress of 2.9 kgf/mm^2 noted with the conforming Kinematic patellar component. Interestingly, though probably to be expected, the area of wear was in inverse proportion – 357.2 mm^2 for the Total Condylar and 439.2 mm^2 for the Kinematic patella. However this difference is not statistically significant. In this study we did not have sufficient information to comment on the difference in volumetric wear.

It has been shown that contact stresses correlate positively with the applied load and correlate inversely with the thickness of the polyethylene (32, 43). High contact stresses are of concern particularly where they approach the yield strength of polyethylene. When thinner than 8 mm, the polyethylene is at risk of accelerated wear because of the marked elevation in contact stress values (3). The polyethylene thickness in both the Total Condylar and Kinematic patella is similary deficient : although thickness at the center is about 8 mm it gradually tapers down to 2.5 mm at the periphery. The damage was observed primarily in the lateral and medial quadrants (quadrants 1 and 3 in fig. 1), producing the "bow tie" or "papillon" pattern of wear. This corresponds to the high stresses that develop in the contact areas at the periphery during articulation of the patella against the femoral condyles and the walls of the trochlea and represents fatigue of the thin contact areas of the implant under cyclic loads. This pattern indeed demonstrates the marked disproportion that exists between the load applied and the inadequate thickness of the polyethylene, specifically at the peripheral contact areas.

For the 12 patients with the most severe damage caused by delamination of the surface, the median time to revision was 90 months, ten months longer than the average time to failure of the entire group. This corresponds to the statement that severity of surface damage correlates with dynamically applied stresses, which are influenced by the weight of the patient and the length of use (11, 22).

Despite the well-known high load borne by the patellar implant during daily activity, it is mechanically constructed as the weakest part of the prosthetic knee. Therefore, taking into consideration the natural structure of the bony patella (47) the implant needs a more thoughtout and better design (32). A thickness of 8 mm of polyethylene over the entire patellar implant at any possible contact area should be the standard (35).

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SAMENVATTING

O. SCHWARTZ, J. AUNALLAH, M. LEVITIN, D. G. MENDES. Het slijtage patroon van verwijderde patella implantaten.

Het vlindervormig polyethyleen slijtage patroon werd nagekeken van 17 patella componenten van 5 Kinematic en 12 Total Condylar kunstknieën, verwijderd na gemiddeld 80 maanden in situ. Arthrosis was telkens de indicatie tot plaatsing van een totale knie prothesis.

Vier slijtage patronen werden onderscheiden (met vermelding van de gemiddelde polyethyleen oppervlakte erbij betrokken) : polijsten in 13 gevallen (gemiddeld 76,5% van de polyethyleen oppervlakte), delaminatie in 12 (70,6% van de oppervlakte), cold flow in 6 (35,3%) en krassen in 3 (17,6%).

Bevestigd werd dat de congruentie bij de Kinematic patella component belangrijk is in het verminderen van de contact stress : 12,9 kgf/mm^2 bij de niet zeer conforme Total Condylar patella component tegenover 2,9 kgf/mm^2 bij de beter passende Kinematic component (statistisch significante verhoging : $p<0{,}002$). Ook was de oppervlakte van slijtage kleiner maar niet significant kleiner bij de Total Condylar (357,2mm^2) dan de Kinematic (439,2mm^2) component. Het gemiddelde lichaamsgewicht was bij de Kinematic patiënten hoger maar niet betekenisvol (74,5 tegen 66 kgr).

De hoge frequentie van poly slijtage van patellaire implantaten duidt op een fundamentele ontwerpfout en vraagt naar verbetering van twee mechanische gegevens : de dikte van de polyethyleen en de congruentie van het gewrichtsvlak.

RÉSUMÉ

O. SCHWARTZ, J. AUNALLAH, M. LEVITIN, D. G. MENDES. Modes d'usure observés sur des prothèses rotuliennes explantées.

Les auteurs ont étudié l'usure «en papillon» de 17 prothèses rotuliennes provenant de 5 prothèses Kinematic et 12 Total Condylar, explantées après 80 mois en moyenne. Il s'agissait dans tous les cas d'une arthrose. Ils ont observé 4 types de dégâts : par polissage dans 13 cas, par délamination dans 12 cas, par fluage dans 6 cas et par griffage dans 3 cas. Les dégâts couvraient 76,5% de la surface du polyéthylène pour le polissage, 70,6% pour la délamination, 35,3% pour le fluage et 17,6% pour le griffage. Les observations ont confirmé l'importance de la congruence du composant rotulien de la Kinematic, dans la réduction des contraintes de surface. Celles-ci étaient significativement plus élevées avec le composant rotulien non congruent de la Total Condylar (valeur moyenne : 12,9 Kgf/mm^2) qu'avec le composant congruent de la Kinematic (valeur moyenne : 2,9 Kgf/mm^2). La surface d'usure était plus petite avec la rotule de la Total Condylar (357,2 mm^2) qu'avec la rotule Kinematic (439,2 mm^2) mais la différence n'était pas significative.

Le poids moyen des patients porteurs d'une Kinematic (74,5 Kg) était supérieur au poids moyen des porteurs d'une Total Condylar (66 Kg) mais la différence n'était pas significative.

L'incidence élevée d'usure marquée au niveau des prothèses rotuliennes montre qu'il y a un défaut au départ dans le design des implants rotuliens, et rend nécessaire une amélioration sur deux points importants : il faut une épaisseur adéquate de l'implant en polyéthylène et un dessin congruent des surfaces articulaires.