Polyethylene delamination in the PCA total knee

Material analysis in two failed cases

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Two patients had severe polyethylene-wear synovitis after total knee arthroplasty for arthrosis. Full-leg length weight-bearing radiographs were diagnostic. The polyethylene of the tibial components showed excessive delamination. The morphology and crystallinity of the polyethylene showed that surface treatment of the material could well be held responsible for the massive wear.

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Delamination is a form of wear in which a thin surface sheet of polyethylene separates from the deeper layers (Hood et al. 1983). Wright et al. (1988) found delamination only in carbon-reinforced ultra-high molecular-weight polyethylene (UHMWPE), due to insufficient bonding of the polyethylene and the carbon fibres during the moulding process. This made it less resistant to fatigue crack propagation than plain UHMWPE (Connelly et al. 1984). However, in a longer follow-up study of retrieved normal UHMWPE material by Landy and Walker (1988), delamination was seen in one third of the cases; it was related to subsurface cracks, cyclic loading of the material (Bartel et al. 1986), and the presence of moulding defects (Rose et al. 1979).

I found delamination in two failed PCA total knees and analysed the morphology and the crystallinity of the polyethylene material.

Case 1

A 55-year-old farmer with a body weight of 90 kg and a length of 173 cm suffered from arthrosis of his left knee after a medial meniscectomy and had an uncemented PCA total knee prosthesis with 7-mm thick tibial plateau. One and two years postoperatively the HSS knee rating score (Insall et al. 1976) was 93 points, and the alignment was perfect on the full-leg length, weight-bearing radiograms. However, at 3 years the score had dropped to 59 points, and there was a severe synovitis. On the weight-bearing radiogram the medial joint space had disappeared completely and there was bone resorption at the edges of the prosthesis.

At revision the destroyed tibial component was removed and a complete synovectomy was performed. Because of the bone resorbed, a new tibial cut was made, and an 11 mm thick component implanted.

Case 2

A 77-year-old woman with a body weight of 95 kg and a length of 161 cm suffered from arthrosis of her right knee. An uncemented PCA total knee was implanted with a tibial component of 9 mm. One year postoperatively the result was excellent with an HSS score of 93 points. On the full-leg length radiogram the mechanical axis was located in the medial compartment, 1.5 cm from the centre. One year later she had mild anterior knee pain, the rating score was still 86 points, but radiographic loosening of the patella was evident. 3 years after surgery, the HSS score had dropped to 63 points, she had synovitis and serious knee pain. On the full-leg length weight bearing radiograph narrowing of the medial joint space was seen with medial shifting of the mechanical axis to 2.5 cm from the centre of the knee. At revision new tibial and patellar components were cemented, combined with a synovectomy. The polyethylene of the tibia showed severe wear, notably delamination.

Polyethylene analysis

Light microscopy

Tibial component sections were taken from a delaminated area in both cases, from a still intact area in the

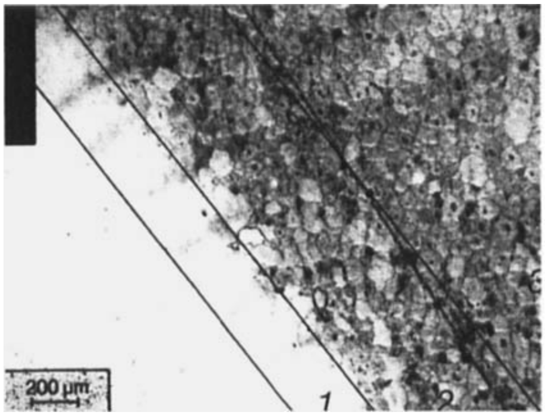

Figure 1. Light microscopy of the reference tibial component.
1. Well moulded surface layer.
2. Poorly moulded subsurface layer.
3. Acceptably moulded deeper layer.

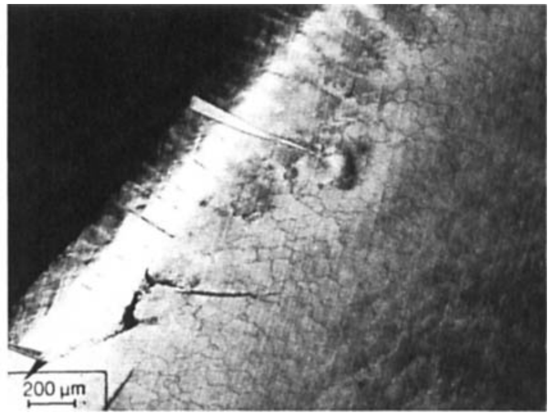

Figure 2. Light microscopy of a macroscopically intact part of the tibial component of Case 2.
Crack formation between the well moulded surface layer and the poorly moulded subsurface layer.

second case, and from an unused tibial component of the primary PCA series as a reference. Sections, 7 µm thick, perpendicular to the surface, were examined by light microscopy. The original polyethylene granules could be identified in all three samples. In the retrieved cases the bounderies of the granules were even more clear than in the reference case. This was in particular evident in the subsurface of the material (Figure 2). In the reference sections a well moulded layer of 300 µm (the same thickness as the delaminated layer) was found, followed by a poorly moulded 600 µm thick layer. Deeper still the moulding was acceptable (Figure 1). This difference in morphology of the layers of the material can only be explained by some sort of surface treatment. In the macroscopically intact part of the worn component, delamination was seen directly under the surface layer (Figure 2). This delamination is theoretically either caused by loading or by a surface treatment during the production process in order to create a smooth surface. However, it was not seen in the reference component, so that loading must be held responsible.

Melting temperature

With differential scanning calorimetry, the melting temperature and the amount of energy necessary to melt the polyethylene were recorded. With these data the crystallinity can be determined (Rose et al. 1980). The material was melted twice. The first heating curve is affected by earlier thermal treatments. In the second heating curve this effect is eliminated, and the original structure is found.

Samples for the tests were taken from the weight bearing surface and the interior part of the two failed tibial components, a delaminated portion from the first case, a non-weight bearing part of the surface from the second case, and the surface and interior of the reference component (Table 1). The low crystallinity of the delaminated part must be explained by degradation of the molecules caused by wear. In the samples from the second case no difference was seen between the non-weight-bearing surface and the interior. This means that the thermal treatment did affect the total thickness of the polyethylene and not only the surface. The slightly higher crystallinity of the weight bearing surface must be explained by a better structure of the crystals themselves under the influence of loading. Another interesting point was that in all samples the crystallinity in the first heating curve was higher than

Table 1. Percentage crystallinity of UHMWPE

	Heating curves	
	First	Second
Case 1		
Weight bearing surface	70	59
Laminated material	55	54
Interior	70	62
Case 2		
Weight bearing surface	68	64
Non-weight bearing surface	63	58
Interior	63	60
Reference component		
Surface and interior	58	54

that in the second curve. From this it can be concluded that Howmedica, who used a polyethylene with a rather high crystallinity, increased this crystallinity further (and, indirectly, the elastic modulus) by their surface treatment.

Discussion

It has been assumed that a high-molecular weight of the polyethylene is a factor in the resistence to wear (Rose et al. 1980) of the acetabular components in total hip replacements.

During the production process the polyethylene powder is melted under compression. It is essential that the temperature is not too high, lest degradation of the ultra-high-molecular weight part of the material can occur (Rose et al. 1979). When this moulding process has not been performed correctly, insufficient fusion is seen between the polyethylene particles. These fusion defects are related to a form of wear, called pitting or crater formation (Rose et al. 1979). The moulding defects can join together and form subsurface microcracks which can lead to delamination.

The chemical structure of polyethylene which gives the least wear has been shown to be an ultra-high molecular-weight material with cross-linked molecules and crystallinity less than 50 percent (Rose et al. 1980). Polyethylene with such a structure has a relatively low elastic modulus. This is important because a low elastic modulus will lead to less contact stress, owing to contact deformation (Wright and Bartel 1986). The surface treatment of the polyethylene manufactured by Howmedica for the PCA primary total knee prosthesis to create a smooth surface is not known to the author, but it is assumed that thermal as well as mechanical methods are used. This treatment can lead to a lower molecular weight at the surface, and to a change in the chemical structure of the polyethylene.

Wear particles cause synovitis; the inflammatory reaction is characterised by a histiocytic and giant-cell reaction. It can also lead to bone resorption at the edges of the prosthesis (Pizzoferrato 1979) with eventual loosening.

The diagnosis of wear in an artificial knee joint is not always easy but it must be suspected in all patients with synovitis and loss of function. Early diagnosis is important for replacement of the polyethylene part to succeed (Uchida et al. 1980).

In the first case the wear could be seen clearly radiographically. In the second case the diagnosis of polyethylene wear was less obvious in spite of synovitis, a reduction in the knee score, and radiographic loosening of the patella. The diagnosis became clear only after full-leg length, weight bearing radiographs had been obtained. Even so, narrowing of the medial joint space could have been easily overlooked if the mechanical axis had not been drawn and compared with that of earlier radiographs. This case shows the importance of weight bearing radiographs at follow-up of patients with arthroplasty of the knee.

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