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Retrieved total hip prostheses

Part II *Wear behaviour and structural changes*

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Polyethylene cups and femoral heads of retrieved total hip prostheses (Charnley 22 mm stainless steel ball, Bioceram 28 mm alumina ball and Müller 32 mm Co–Cr–Mo alloy ball) were observed by the naked-eye and scanning electron microscopy. Cross-linked cups irradiated with gamma radiation in heavy high doses of 100 Mrad were included. On the weight-bearing surface of the cups non-gamma irradiated, carpet-like conspicuous fine fibres, scratches and fine crevices for the 22 mm ball, scale-like with rough and fine crevices for the 28 mm ball, and scale-like structures and many scratches for the 32 mm ball, were observed, mainly. On the whole, the number of crevices for the 32 mm ball was fewer than that for the 22 and 28 mm balls. The weight-bearing areas of the gamma-irradiated cups presented a clearly outlined pattern, irregularly lined with smooth ripples of about 0.1 μm. The scratching, flaking and delamination, characteristic of non-gamma irradiated polyethylene, were not observed at all. These findings indicate that wear is very small for gamma-irradiated polyethylene. For references, the weight-bearing surfaces of retrieved total knee prostheses were compared.

1. Introduction

In Part I [1] the following points from the investigations of the retrieved total hip prostheses were reported.

1. Measurement of wear, including creep deformity, of the polyethylene cups.
2. Examination of fusion defects in the cups.
3. Measurement of the changes of the mechanical properties of the polyethylene cups.

In this work, we have focused on observation of surface changes, e.g. wear and degradation, etc., and structural changes.

2. Materials and methods

The materials were obtained from patients suffering from slight loosening of the components and from late infections only between the bone and the components, or obtained in an autopsy. The retrieved hip prostheses used for the following observations are shown in Table I.

The retrieved prostheses were Charnley (22 mm stainless steel head), T-28 (28 mm stainless steel head), Bioceram (28 mm alumina head) and Müller (32 mm Co–Cr–Mo alloy head) implants.

The surfaces of the polyethylene cups mainly and the femoral heads were observed by naked-eye and scanning electron microscopy. The features of the weight-bearing and the non-weight-bearing surfaces were compared, and features of the wear behaviour and degradations on the surfaces were observed.

For reference, the surfaces of polyethylene tibial plateaus and femoral condyles of the retrieved total knee prostheses were compared.

3. Results and discussion

3.1. Observation of the surface of polyethylene cups

3.1.1. Gross observation

If a remarkable physical change has occurred on a polyethylene cup during implantation, the change can be readily detected by gross observation with the naked eye. Typical detectable changes include discoloration, deformation, cracking, abrasion, delamination, and perforation.

In the case of polyethylene cups without gamma radiation of 100 Mrad, a smooth and glossy surface was seen on the weight-bearing surface. However, in many cases, the non-weight-bearing surface was

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TABLE I Retrieved total hip prostheses observed by SEM

Prostheses	Cup thickness (mm)	Implanted periods
Charnley	9	12 y
(22 mm)	10.5	11 y
	9	10 y
Bioceram	7	11 y 11 mon
(28 mm)	7	10 y
	7	8 y
	8	10 y
Müller	8.5	15 y
(32 mm)	8.5	13 y 10 mon
T-28	6	8 y 5 mon
(28 mm)	7	12 y 7 mon
	7	6 y
	7	9 y
SOM	7	13 y
cross-linked with	7	14 y
100 Mrad (28 mm)	7	14 y
SOM cross-linked with 100 Mrad (32 mm)	9	9 y 8–11 mon

degraded and changed, being rough and yellow-brown in colour. It should be noted that the polyethylene is not always responsible for these changes. The prosthetic design, surgical technique, polyethylene processing, and counterface properties are sometimes a major cause for such deterioration, as detected by gross observation.

In the case of the polyethylene cups subjected to gamma radiation of 100 Mrad, a smooth and glossy surface was seen on the weight-bearing surface; the non-weight-bearing surface was not degraded nor changed, and the colour was unchanged. The polyethylene cups irradiated with 100 Mrad gamma radiation were brown in colour [2, 3].

3.1.2. Scanning electron microscopic observation

The most widely applied method for observing the surface of retrieved polyethylene cups is scanning electron microscopy (SEM). This is probably because the wear of polyethylene surface produces defects of a size that SEM allows us to see most clearly, when compared with other observation methods.

3.1.2.1. Non-weight-bearing portions. On the non-weight-bearing portions, flaws or machine marks that had been made during production were seen (Fig. 1). No abrasion was seen. Hollows, scratch lines and craters were observed. Some portions revealed an irregularly lined pattern of one to several micrometres of smooth ripples. This was taken to be the degradation in the living body (Fig. 2).

Abrasive damage and cracks were observed in many specimens (Fig. 3).

In the case of the SOM (Shikita, Oonishi and Mizuho Medical Instruments Corporation) of gamma-irradiated polyethylene, the non-weight-bearing portion presented an irregularly lined pattern of smooth and low ripples of about 0.1 μm, far smaller than those of the non-gamma-irradiated polyethylene (Fig. 4a, b) [2, 3].

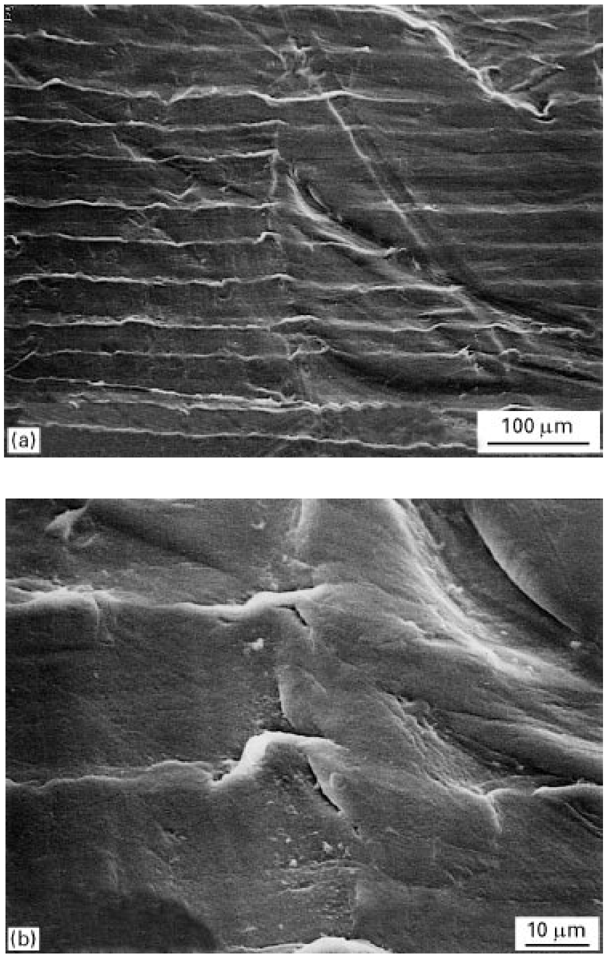

Figure 1 Non-weight-bearing portions of a polyethylene cup (by SEM).

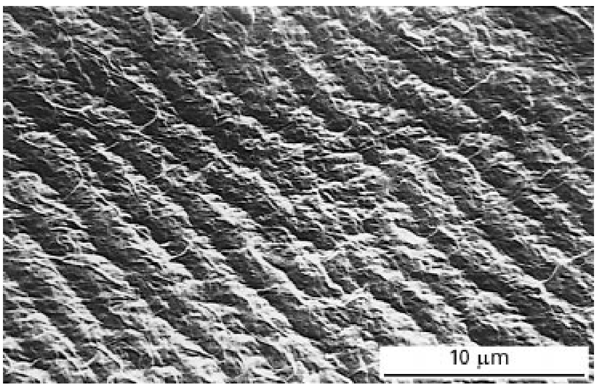

Figure 2 Degradation of the non-weight-bearing portion of a polyethylene cup (by SEM).

3.1.2.2. Weight-bearing portions. Surface changes on the weight-bearing areas were classified into two groups; a group with a rather smooth surface (T-28, Bioceram) (Fig. 5), the other with carpet-like conspicuous fine fibres (Charnley) (Fig. 6).

Fine, but not sharp, unevennesses were observed in the group with a smooth surface at higher magnifications (Müller, 1-T-2, 2-B-6) (Fig. 5). These differences

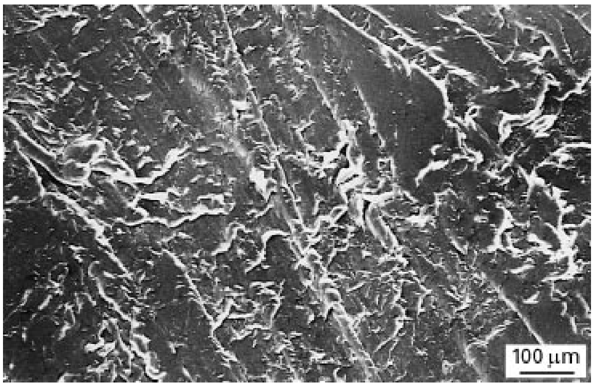

Figure 3 Non-weight-bearing portion of a polyethylene cup (by SEM).

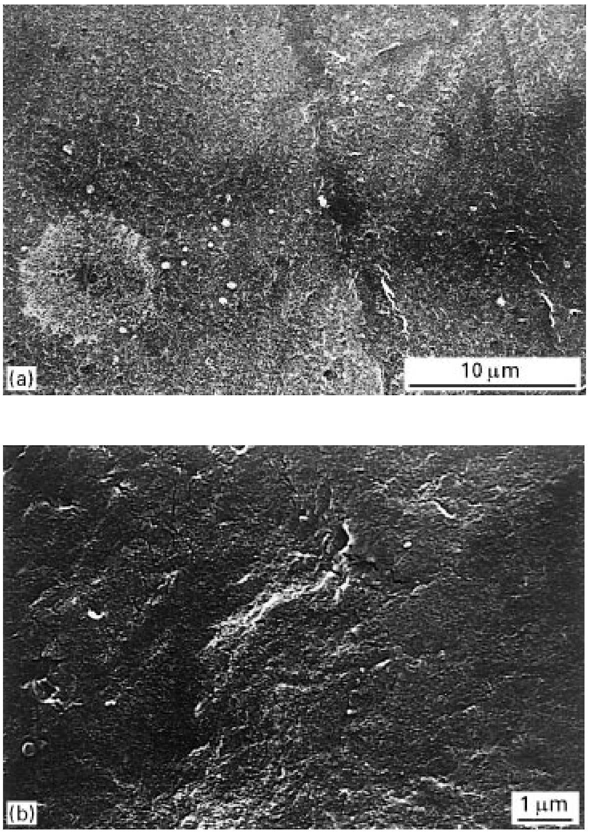

Figure 4 (a) Non-weight-bearing portions of a polyethylene cup with gamma irradiation of 100 Mrad. (b) Higher magnification of (a).

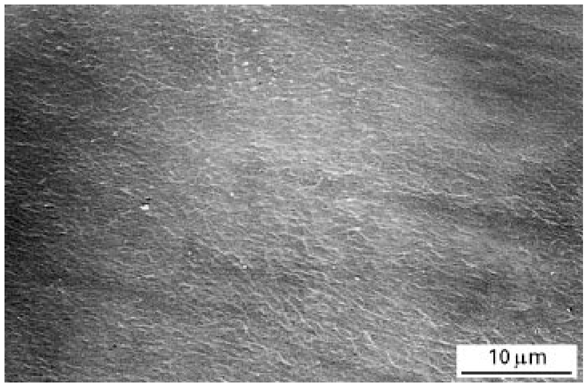

Figure 5 Weight-bearing area in a group with a rather smooth surface.

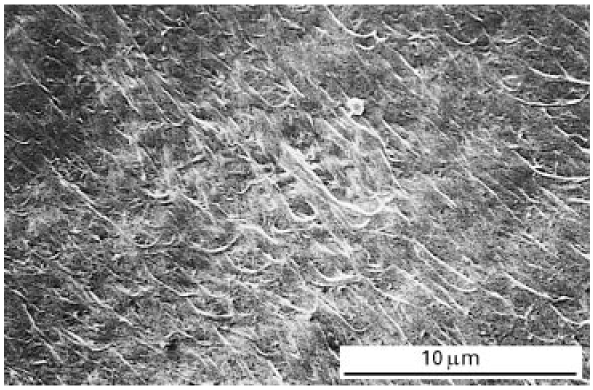

Figure 6 Weight-bearing area in a group with carpet-like conspicuous fine fibres.

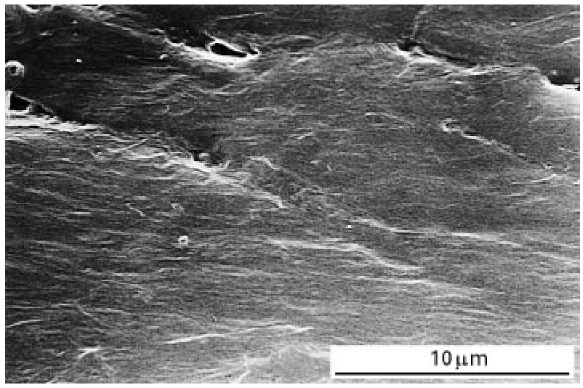

Figure 7 Fine crevices on the weight-bearing area.

in surface structure, however, are not directly related to the degree of wear.

Some specimens had fine crevices (Fig. 7).

In some crevices, bridge-like fibrils were seen (Fig. 8). According to Rose *et al.* [4], the fibrils connect the boundaries of fused polyethylene particles, suggesting that the crevices were developed between fused particles. Scratches were often seen on Müller and T-28 cups. These scratches were thick and had smooth edges.

In the case of SOM of gamma-irradiated polyethylene, retrieved 13 and 14 years after surgery, the non-weight-bearing portion presented an irregularly lined pattern of smooth and low ripples of about 0.1 μm, far smaller than those of the non-gamma-irradiated polyethylene (Fig. 4a, b). The weight-bearing portion presented a more clearly outlined pattern, irregularly lined with smooth ripples of about 0.1 μm. The scratch flaking, delamination and folding phenomena, characteristic of non-gamma-irradiated polyethylene, were not observed at all. These findings indicate that wear is very small for gamma-irradiated polyethylene (Fig. 9a, b) [2, 3].

Features peculiar to each prostheses are given below.

(a) *Bioceram* (*28 mm alumina head*). On the non-weight-bearing area, the surface was smooth overall; however, it had local damage, such as crevices (Figs. 1 and 3). On the weight-bearing area, the surface was smooth overall; however, at higher magnifications, the

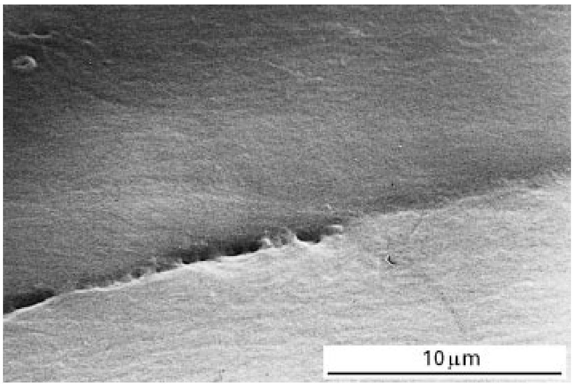

Figure 8 Bridge-like fibrils seen in the crevices.

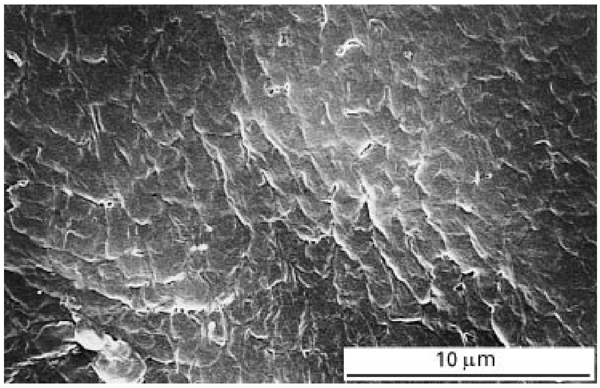

Figure 10 Scale-like defects with a rough napp on the weight-bearing area (Bioceram).

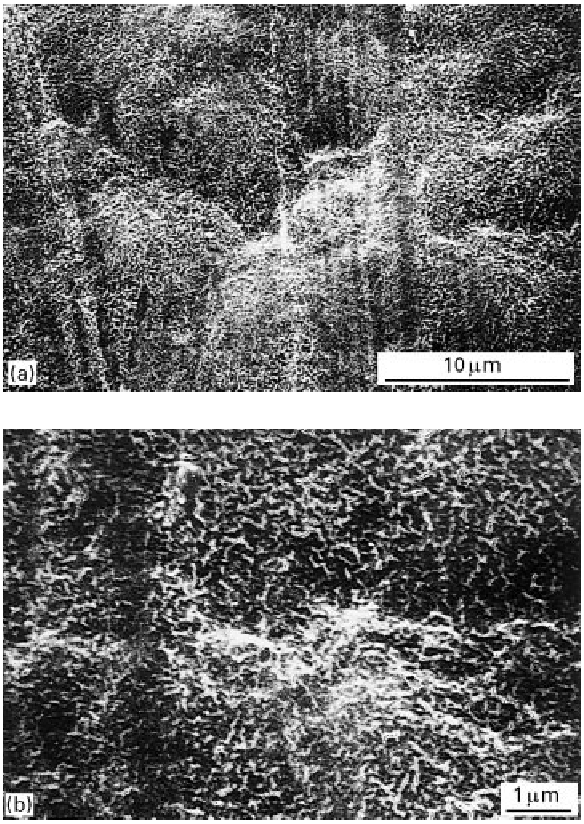

Figure 9 (a) Weight-bearing area of a polyethylene cup with gamma radiation of 100 Mrad. (b) Higher magnification of (a).

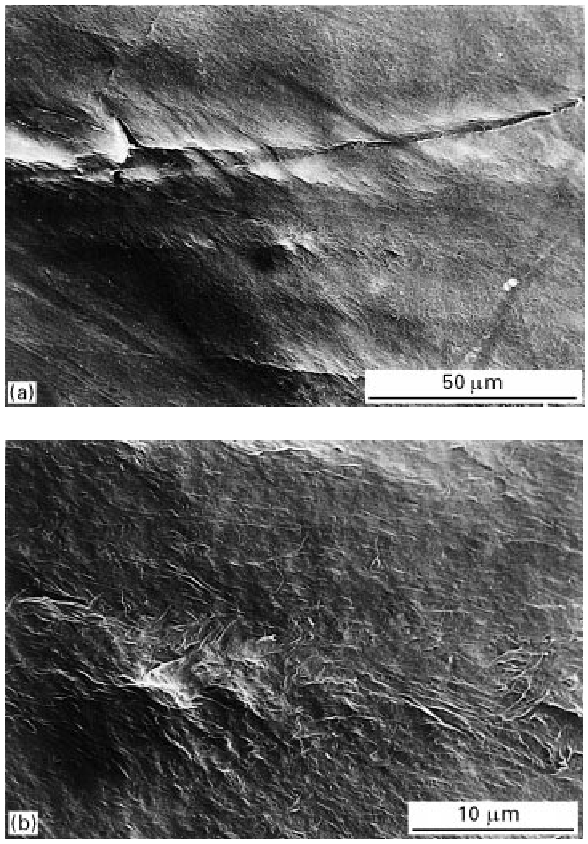

Figure 11 (a) Striate unevennesses on the non-weight-bearing area. (b) Higher magnification of (a) (Charnley).

surface became scale-like with a rough nap, and fine crevices were observed (Fig. 10). There were no evident scratches.

(b) *Charnley* (*22 mm stainless steel head*). On the non-weight-bearing area, striate unevenness was seen (Fig. 11a, b), many fine crevices were observed overall, and their directions were not uniform. On the weight-bearing area, the surface was smooth overall; however, at higher magnification, carpet-like conspicuous fine fibres were observed (Fig. 12). Scratches and fine crevices were seen here and there. However, the crevices were rather fewer on the weight-bearing area than that on the non-weight-bearing area.

(c) *Müller* (*32 mm Co–Cr–Mo alloy head*). On the non-weight-bearing area, striated unevenness was seen. On the weight-bearing area, the surface was smooth overall. However, at higher magnification, scale-like structures were seen (Fig. 13). Many scratches were observed; however, few crevices were seen.

On the whole, on comparing the three kinds of prostheses, the number of crevices on the polyethylene cups of Müller was fewer than that of Charnley and Bioceram. It may be that the production of crevices on the polyethylene cups in combination with a large head is less than that of a small head.

Remarkable structures formed on retrieved polyethylene cups as a result of wear with the hard counterpart head, include scratches, tearing, cracking and deformation. Most of the defects may be due to abrasive wear of the polyethylene that has a much lower yield strength than the metal and ceramic counterparts, but elucidation of the exact mechanism

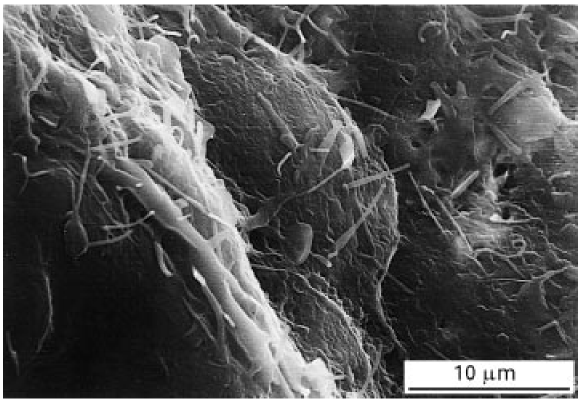

Figure 12 Carpet-like conspicuous fine fibres on the weight-bearing area (Charnley).

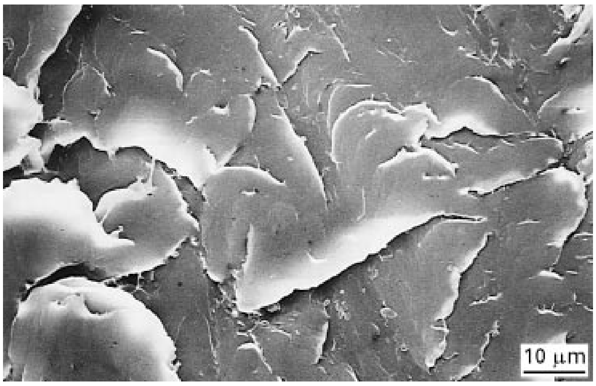

Figure 13 Scale-like structures on the weight-bearing area (Müller).

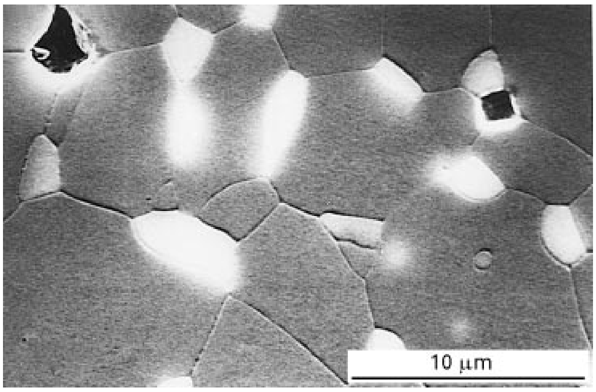

Figure 14 Weight-bearing area of the alumina femoral head.

of such defect generation needs comprehensive study, other than SEM observation.

3.2. Observation on the surface of the femoral heads

In the case of the alumina femoral heads observed by SEM, some weight-bearing areas appeared burnished in some places (Fig. 14). In contrast, readily observable burnishing and scratches were produced on the weight-bearing parts of the metal heads (Fig. 15).

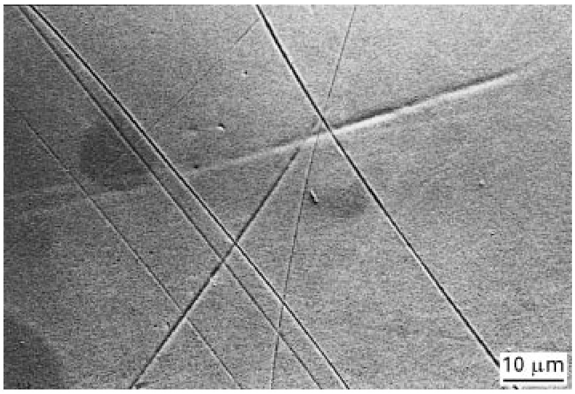

Figure 15 Weight-bearing area of the metal femoral head.

TABLE II Retrieved total knee prostheses observed by SEM

	Implanted period (y)	Retrieval cause
PCA (Co–Cr–Mo) (cemented)	3	Late infection
KOM (alumina) (non-cemented)	6	Autopsy

3.3. Observation of the surface of retrieved total knee prostheses

For reference, retrieved total knee prostheses using the combination of alumina condyle and polyethylene tibial plate, and using the combination of Co–Cr–Mo alloy condyle and polyethylene tibial plate were compared (Table II).

We observed three cases using the combination of an alumina condyle and polyethylene tibial plate without loosening, including two post-mortem cases (6 months and 6 years after implantation) and a case with infection between bone and component (1 year after implantation). We also studied an infected case of a non-loosened PCA made of a combination of Co–Cr–Mo alloy and polyethylene (3 years after implantation). The surfaces of the prostheses were observed by SEM and metallographic microscope.

3.3.1. Polyethylene surface of tibial plates

The polyethylene surface against alumina was found to have gently sloping machine marks, measuring one to several micrometres, left on the non-weight-bearing areas, while machine marks on the weight-bearing areas completely disappeared 6 years after surgery, though some remained in place at 6 months and 1 year after implantation. Overall observation revealed almost all surfaces to be smooth and burnished without scratches or pits. The polyethylene folding phenomenon, which is thought to be caused by three-body wear occurring as a result of the interposition of polyethylene wear particles between components, was also seen in places, though to a small extent. It was suspected that part of the tip of this folded polyethylene was torn into debris when a force was transmitted on to the tip from the femoral component (Fig. 16a, b).

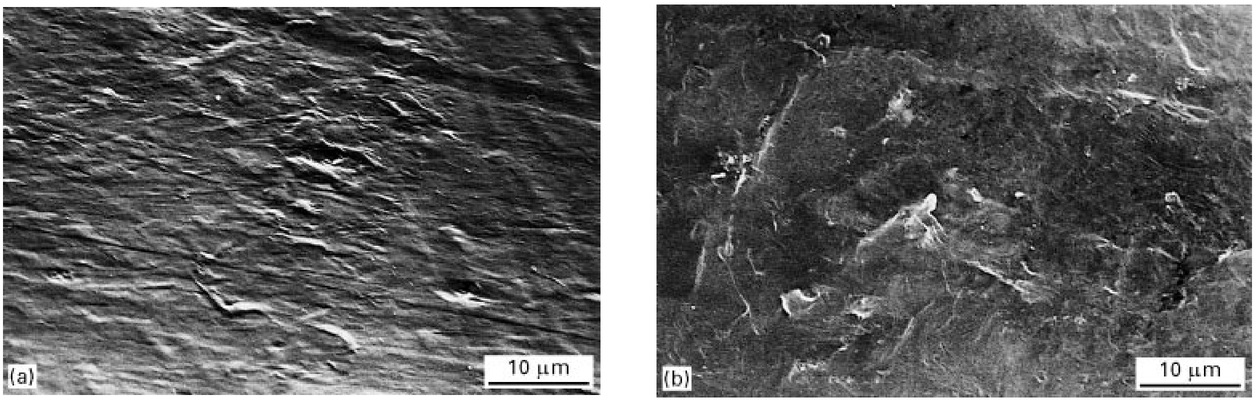

Figure 16 Tibial plates against alumina femoral condyles taken *post-mortem* without any complications 6 years after a cementless replacement. (a) Non-weight-bearing surface of polyethylene of the tibial plate. (b) Weight-bearing surface.

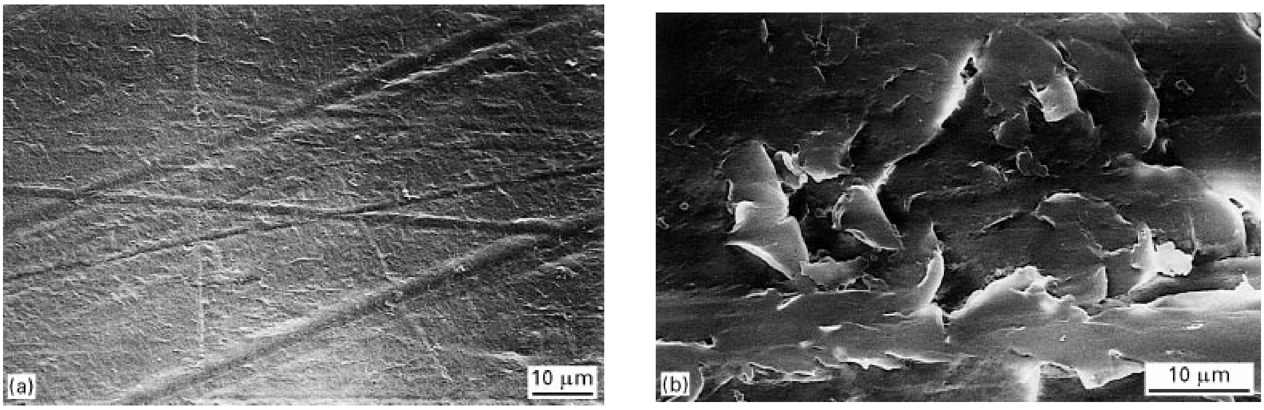

Figure 17 Tibial plates against Co–Cr–Mo alloy femoral condyles taken from a patient with late infection at the bone–tibial component 3 years after surgery. (a) Non-weight-bearing surface of polyethylene of tibial plate. (b) Weight-bearing surface.

In the case of a polyethylene surface against Co–Cr–Mo alloy, burnishing was seen in sites where the machine marks disappeared, and small scratches were observed at these sites 3 years after surgery. The folding phenomenon was observed frequently, and the folding sites mingled with scratches in many places (Fig. 17a, b) [5, 6].

3.3.2. Polyethylene surface of patella components

As a tibial component has a concave or flat surface while a patella component has a convex surface, their surfaces wear differently. Owing to the convex shape, and perhaps due to surgery or removal of the component, many artificial scratches were present over the surface of the patella; however, it was unclear when the scratches occurred – before use, during implantation, or at the time of removal. On the sliding areas without artificial scratches, burnishing sites mingled with folding sites. It was especially noted that there were many dimples, measuring 2–3 μm diameter. Similar changes were seen on the polyethylene articulating against Co–Cr–Mo alloy and alumina (Fig. 18).

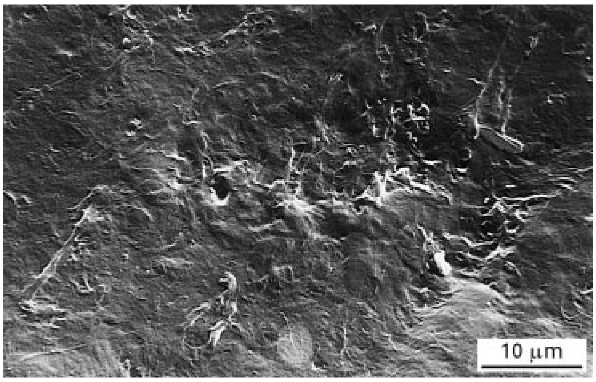

Figure 18 Polyethylene surface of a patellar component.

3.3.3. The surface of the femoral component

On the alumina femoral components, some sliding areas appeared burnished by SEM observation; however, no measurable change was observed by light microscopy. In contrast, observable burnishing and scratches were produced in the sliding areas of the Co–Cr–Mo alloy (Fig. 19a–d) [6].

4. Conclusion

A tremendously large number of retrieval studies on hip prostheses have revealed, macroscopically and microscopically, severe degradation of polyethylene cups, mostly due to wear, but surprisingly few studies have been devoted to preventing polyethylene wear. This wear seems to be induced primarily by two

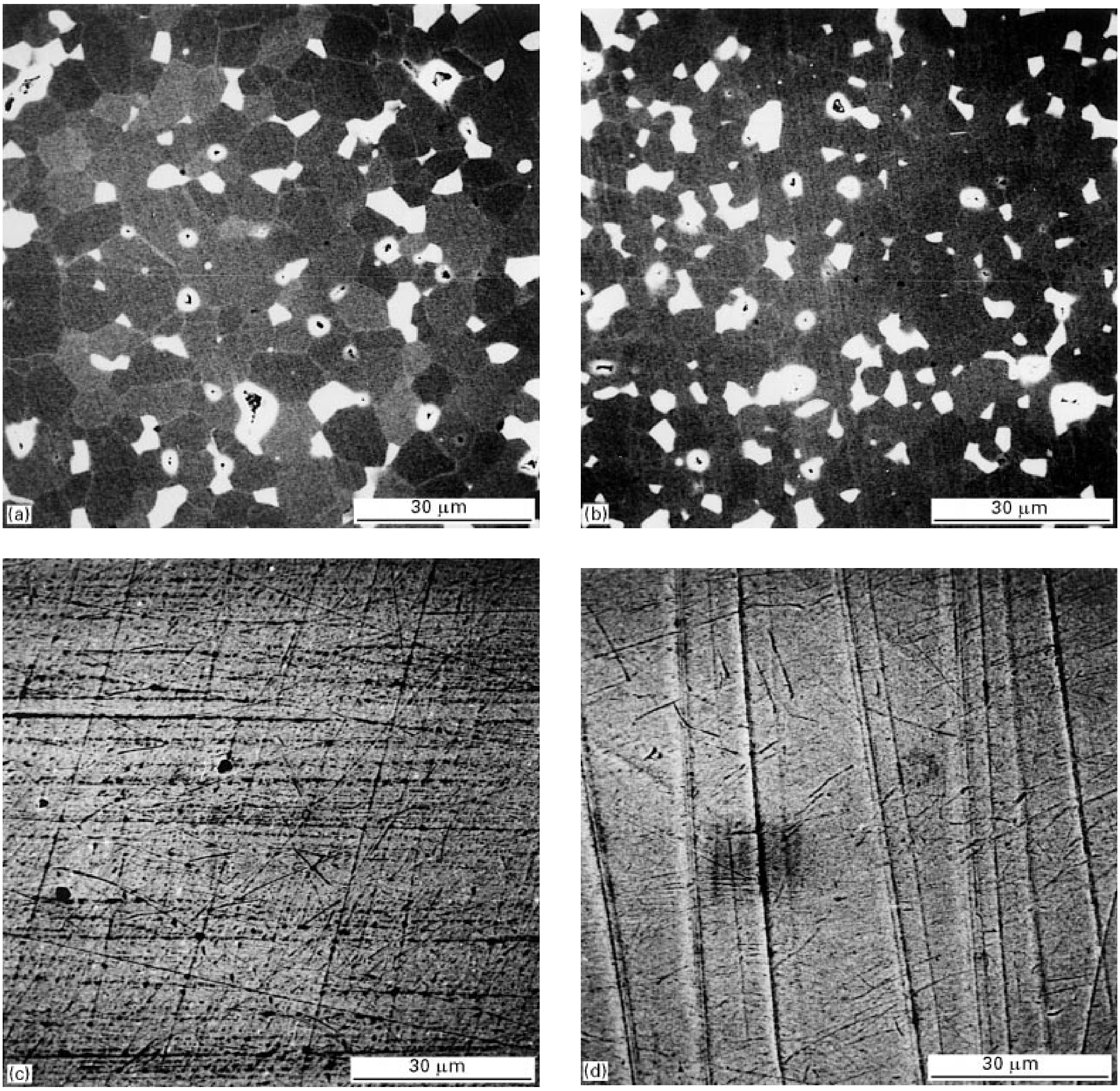

Figure 19 (a) Non-weight-bearing area, and (b) weight-bearing area of an alumina femoral component (SEM). (c) Non-weight-bearing area, and (d) weight-bearing area of Co–Cr–Mo alloy femoral component (SEM).

causes; ageing of gamma-irradiated polyethylene sterilized in the air and low yield strength of polyethylene compared with the hard bearing counterparts. Aged and weak polyethylene must be vulnerable to fatigue, resulting in abrasion. If the abrasive wear of polyethylene cups starts from chain scission in the subsurface region of the polyethylene, it is essential to know the microscopic events occurring in the polyethylene interior during use. It follows that observation of retrieved prostheses should not be limited to the outermost surface of the retrieved materials, but be extended to the subsurface region. For this purpose, ultrasonic microscopy and ESR seem to provide a good means. Improvement of the poor wear-resistance of polyethylene will be accomplished when clear observation of internal defects of polyethylene becomes possible.

At present, in the investigated results from our long-term clinical experiences and retrieved prostheses, the wear of polyethylene cups irradiated with gamma radiation in heavy high doses of 100 Mrad was the lowest, and this material was supposed to be the best polyethylene available.

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