Failure analysis for degradation of a polyethylene knee prosthesis component

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Short communication

Failure analysis for degradation of a polyethylene knee prosthesis component

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1. Introduction

It is known that wear of tibial components must be made of ultra high molecular weight polyethylene being the limiting factor that compromises the long-term performance of joint prosthesis [1–3]. In knee prostheses the wear occurs on the surface of the tibial plate which it is contact with femoral component, commonly metallic, see Fig. 1a. Previous studies established that the wear rate of a polyethylene tibial average particles size is about 5.6×10^{10} particles/g [4,5]. The aim of this work was to establish the causes that originated the failure of a tibial base component from a knee prosthesis, which was removed after 7 months of service from a 60 year old female, 65 kg weight and 1.5 m height, active patient. The studies conducted to characterize the tibial base component by visual inspection initially and scanning electronic microscope (SEM), showing that there was a failure due to a sever wear, so degradation and crystallinity were measured by fourier transform infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC) tests, respectively; as previous results showed a lower properties than expected, then gel penetration chromatography (GPC) was made in order to measure the polyethylene tibial base molecular weight.

2. Experimental

Fig. 1a shows a knee prosthesis which consists of three components: femoral, tibial, and tibial tray. Visual inspection shows that the tibial plate component was practically destroyed due to a severe surface damage by contact stresses, damaged surface showed a different color, Fig. 1b and c. In order to verify this surface, morphological characterization of the polyethylene tibial plate was carried out by SEM, polyethylene samples were coated by sputtering with a gold layer of about 25 nm, since this material is not an electric conductor. Infrared spectroscopy analysis was carried out in a thin section

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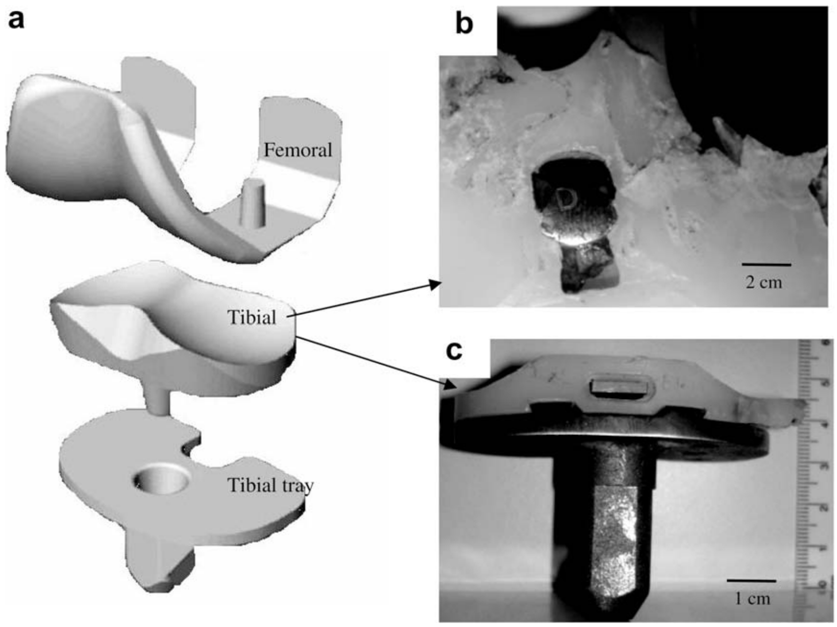

Fig. 1. Knee prosthesis: (a) schematic prosthesis components, (b) top view of the tibial base showing a severe damage and (c) front view of the tibial base.

specimen of the tibial plate with a weight of approximately 5 mg, using a spectrometer FTIR NICOLET 500, in order to get composition and degradation of the tibial plate polymer, the final spectrum represents the average of 30 scans with a resolution of 4 cm^{-1}. Differential scanning calorimetry measurements of specimens taken from the tibial plate were undertaken in order to measure percentage of crystallinity by means of a MDSC apparatus model 2920 manufactured by TA Instruments; this instrument was calibrated using an Indium standard to obtain the tibial plate polymer formation enthalpy and compare it with the total heat fusion value of a completely crystalline polyethylene to get its crystallinity grade, the temperature was varied from 0 to 150 °C, heating at a rate of 10 °C/min. Finally to measure the polyethylene molecular weight of the tibial plate, gel penetration chromatography analysis was made in ALLIANCE GPCV-2000 equipment with a small amount of polyethylene dissolved in triclorobencene at 140 °C.

3. Results and discussion

Fig. 1b shows the polyethylene tibial base surface with severe wear caused by cyclic straining on the contact area between the tibial plate polymer and femoral component, which could be enhanced to the brittleness of the polymer. SEM micrograph, Fig. 2a shows delamination, besides it is seen some polymer lamellas coming off from the surface, this could be due to a possible polyethylene degradation. FTIR spectrum obtained from a thin section specimen of tibial base component, Fig. 2b shows different picks and one about 1716.81 cm^{-1} attributed to carbonyl group; this behavior can be attributed to material degradation, as suggested by other researchers [6] also other researches concluded [7,8] that this spectra in a higher resolution equipment had two peaks at 1742 and 1713 cm^{-1}, corresponding to esters and acids, respectively, this is a direct evidence of broken chains in the polyethylene. On the other hand, DSC thermograms shown in Fig. 2c indicate that at 137.9 °C, on heating, the melting of the crystalline regions of this semi-crystalline polymer occurs. Though it is known that some polymers are partially crystalline, considering the total heat fusion for a completely crystalline polyethylene of $\Delta H_m = 293$ J/g [7], crystallinity degree is calculated as the ratio between experimental heat fusion ΔH_e and ΔH_m, so % $C = 100^* \Delta H_e/\Delta H_m$, obtaining an experimental crystallinity of 65.4% on heating, this shows lower crystallinity degree than expected. Some researches [6–9] determined that the sterilization of prostheses by gamma radiation applying doses of 2.5 Mrads in air produces degradation, which is the most common practice used by the majority of manufacturers [10], the irradiation the polymer undergoes surface oxidation that leads to chemical changes, reducing the molecular weight polyethylene and thus its properties, this could be one of the polyethylene degradation and low crystallinity degree causes. Finally, molecular weight was measured by GPC technique, as it was expected a polyethylene of ultra high molecular weight, the molecular weight (Mw) of the tibial base polyethylene was 16,6855 g/mol, the average molecular weight of a polyethylene (medical grade) should be exceeding 1.5×10^6 g/mol [11], being this result ten times lower than the minimal value expected this is an evidence that tibial polyethylene corresponds to a commercial degree, besides of being degradated by sterilization by gamma radiation, it gives as a result a polyethylene of a bad quality, this explain the severe damage of the tibial base component, thus for preventing future failures, a great deal of care over polyethylene selection it must be take.

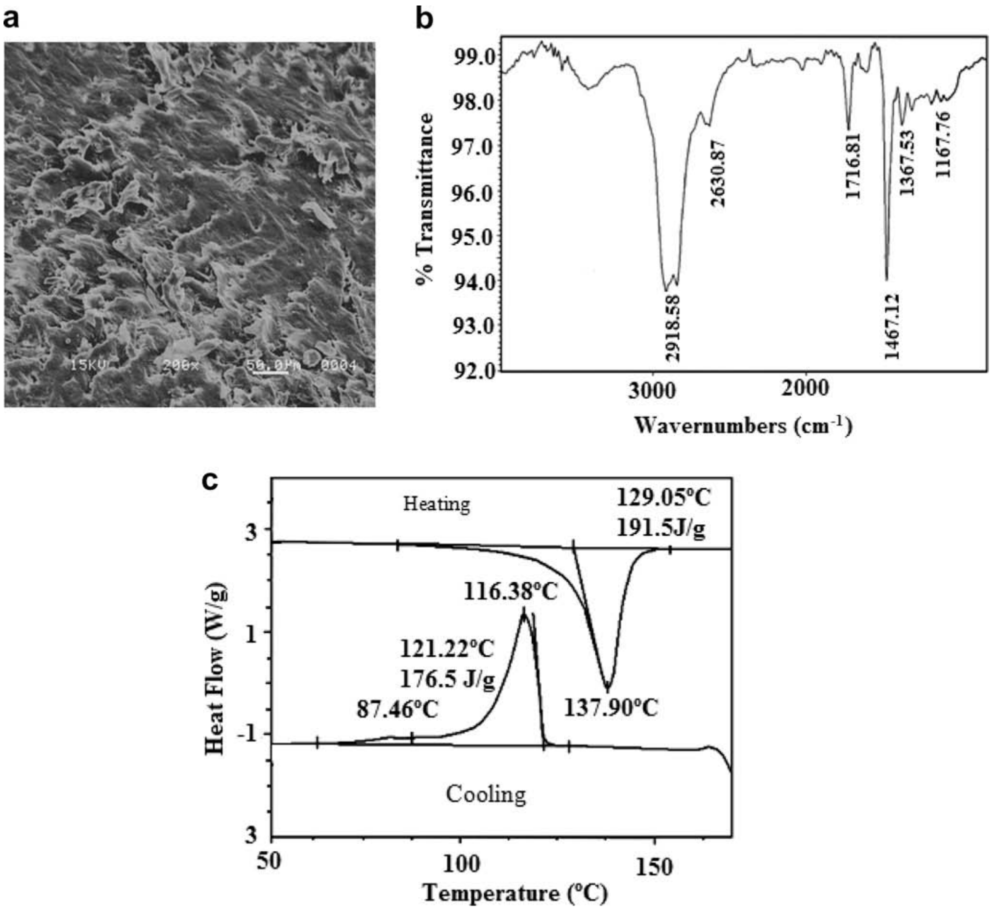

Fig. 2. Tibial base component: (a) SEM micrograph shows delamination, (b) FTIR spectrum and (c) DSC thermograms.

4. Conclusions

From the results of this investigation after performing the analysis of the polyethylene tibial base damage from a knee prosthesis, conclusions can be summarized as follows:

(1) Polyethylene tibial base component damage was caused by a sever wear caused by cyclic straining on the contact area between the tibial base and femoral component, due to a brittleness polymer, occurring after 7 months of use in an active patient.
(2) The presence of carbonyl groups is associated to the degradation of the polyethylene, these were originated during processing and sterilization of the prosthesis; as the polymer degrades it becomes brittle, which makes it prone to suffer severe wear by delamination.
(3) The tibial base polyethylene had low crystallinity, it showed a typical discoloration, furthermore of modifying its properties.
(4) The proposed sequence of failure is: because of the lower mechanical properties of the tibial base polyethylene led to a severe wear, which promoted stress concentration on the prosthesis, resulting in accelerated failure of the tibial base.
(5) In order to prevent wear failure, initial polyethylene molecular weight must be controlled, precise control of crystallinity and degradation of the tibial base polyethylene must be taken after sterilization.

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