Surface analysis of early retrieved polyethylene tibial inserts for both knees in total knee replacement

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ABSTRACT

This study involves the failure analysis of a pair of ultra-high-molecular-weight-polyethylene (UHMWPE) knee tibial inserts from Scorpio® fixed-bearing total knee system by Stryker, which were retrieved from Total Knee Replacements (TKR) that was performed on 64 years old male patient with periprosthetic joint infection detected on both knees. Although the implants were removed due to infection, surface analysis was essential to be studied in order to analyse the surface damage mode of short-term implants. This study reports relevant damage mechanisms seen in early-retrieved UHMWPE tibial inserts (implanted for 6 and 8 months) and further analysis of chemical, physical and mechanical properties that possibly accompanied with failure. The surface characterization was done using a 3D laser microscope and Scanning Electron Microscope (SEM) to evaluate surface damage and dimensional change of both UHMWPE tibial inserts. Nano-indentation is used to measure the hardness and elasticity modulus of the tibial inserts. Attenuated Total Reflection-Fourier Transform Infra-Red (ATR-FTIR), Differential Scanning Calorimetry (DSC) and Gel Permeation Chromatography (GPC) were used to characterize the chemical and physical properties of the inserts. In present study, retrieved polyethylene inserts with short implantation duration was considered to have high-grade wear modes. The high incidence of micro pits (with the average depth of 27.5 μm for 6 months insert and 18 μm for 8 months insert) and scratches as the observed surface defects strengthen the role played by the particles upon defects generation for both tibial inserts. The average surface roughness of 6 and 8 months inserts were 1.6798 μm and 1.2376 μm, respectively. The rough surface (4.207 μm) of region 4 at the lateral compartment proves that the 6 months tibial insert suffered more damage due to loosening defect where the radiolucencies (the gap between bone and cement) were seen below medial and lateral aspects of the tibial tray. Our data demonstrated a strong association between the change of molecular weight and degradation of mechanical properties with wear for both inserts. The oxidation induced wear mechanism was observed on 6 months old insert due to the presence of delamination features with the evidence of in vivo oxidation from IR analysis.

1. Introduction

Total Knee Replacement (TKR) is one of the most executed elective surgical procedures in orthopaedic surgery worldwide. TKR has been found to relieve pain due to osteoarthritis and it is effective in improving function and restoring the quality of life in patients [1]. In the United States, the demand for primary TKR is projected to grow by 673% (3.48 million) from 2005 to 2030 [2]. In general, TKR consists of three main components: the metal femoral component, metal tibial component, and polyethylene tibial insert. However, over time, a knee replacement may fail for a variety of reasons and may need a second surgery which is termed revision TKR. Evidence from previous studies suggests that knee replacements can last at most 15–20 years [3]. The longevity of knee replacement implants can be influenced by the condition of patients such as age, weight, gender, and activity level [4]. Polyethylene damage and wear have been considered as threats to the long-term survival of TKR [5–7]. Failure most commonly occurs in the form of fatigue and adhesive wear that generates submicrometer particulate debris which then cause osteolysis around the implant components, ultimately leading to loosening and failure of the TKR [5–9].

In previous failure analysis, TKR which fails within 5 years of the index operation is categorized as an early failure [10]. Fehring et al. [10] claimed that the reasons for early failure were infection (38%), instability (27%), failure of ingrowth of a porous-coated implant (13%), patellofemoral problems (8%), and wear or osteolysis (7%). Sharkey, P.F. et al. [11] reported that the most common causes of early failure which less than 2 years after the index operation are infection and instability. Infection was found to be the predominant mode of failure to early failure mechanisms of TKR. However, infection can be difficult to diagnose and require multiple approaches to find the cause of failure [12]. Previous studies on surface analysis of early retrieved tibial inserts (less 37.8 months of implantation time) which were retrieved due to infection have shown evidence of surface wear damage based on Hood grading scale system [13]. This finding has raised a question of whether polyethylene wear is associated with the increases risk of Periprosthetic Joint Infection (PJI). Generation of wear debris from polyethylene implants can causes a distinctive foreign body reaction [14]. However, the correlation between polyethylene wear and infection remain unexplained especially for early retrieved study.

Although there is no clear correlation between PJI and the surface wear damage, it is still essential to analyse the surface of early retrieve implant in order to study its wear mechanism. Diabb et al. [5] reported that the analysis on 7 months implanted polyethylene tibial insert indicated that there was mechanical properties degradation of insert that lead to severe wear damage. The polyethylene wear mode that being observed on implant can be classified into high-grade wear (scratching, pitting, metal embedding, and delamination) and low-grade wear (burnishing, abrasion, and cold flow) [15]. In which, low-grade wear was more commonly observed in mobile-bearing knees, whereas high-grade wear was more commonly observed in fixed-bearing knees [15]. The formation of wear damages is more likely to correlate towards each other. The wear debris that peels off from the implants or formed during the articulation motion of implants will act as third body particle which later caused the formation of another wear [16]. Hence, the study toward the surface wear of an implants is essential in order to improve its surface properties which further improve its longevity. There are a limited number of retrieval studies performed for early retrieved tibial insert component. By analysing the surface of an early retrieved implants, the factors that may initiate the formation of wear damage on the implants will be able to be studied. Thus, methods to improve the surface properties and longevity of implants will be able to be classified in the future. This study will be focusing on to identify the wear damage modes of an early-retrieved UHMWPE tibial inserts and reveal the wear mechanism on tibial insert which undergoes revision surgery within 1 year period of their index arthroplasty. This study was conducted on retrieved knee implants which were obtained from a 64 years old male patient who complained about left knee pain and swelling for 1 month duration after undergoing bilateral total knee arthroplasty for 8 months and 6 months for right and left knee respectively. Although the implants were removed due to infection, however the surface analysis were essential to be studied in order to analyse the surface damage mode of a short-term implants. The main focus of this study is to describe the severity and location of surface damage qualitatively which can discuss the damage mechanism on the early-retrieved implants. The analysis on the worn surface polyethylene will provide information about the wear damage mode and mechanism of the UHMWPE.

2. Material and method

2.1. Retrieved sample history

Both left and right retrieved knee implants (implanted for 6 and 8 months) were obtained from a 64 years old male patient. Patient underwent bilateral primary TKR with both Scorpio® Knee System. The previous surgery procedures were carried out in 2017 at another medical centre. The information on patient's activity level prior to surgery is unable to retrieved since the primary surgery was done in another medical centre. Patient gave no history of trauma to the left knee and no history of fever. There was also no history of other source of infection prior to onset of symptoms.

The left knee was originally aspirated at a private centre and joint fluid culture grew coagulase negative Staphylococcus epidermidis resistant to Methicillin. Oral antibiotic was initiated and the patient was referred to University Malaya Medical Centre (UMMC) for further management. Left knee was noted to undergone bilateral knee swelling with tenderness. There was no sinus tract and both knee range of motion was 0–110 degrees of flexion. Besides that, there were no obvious skin changes and surgical scars over both knees were well healed. Furthermore, loosening of left knee implant with osteolysis posterior to femoral component and under the tibial tray was seen on bilateral knee X-rays (Fig. 1a). The patient underwent first stage revision of left knee which involved removal of the implants and insertion of articulating antibiotic cement spacer. Later, in order to rule out a periprosthetic joint infection of the right knee, an aspiration of the knee was performed in the same sitting and was found to be suggestive of periprosthetic joint infection with high leucocyte count > 2000/μl, grew gram positive cocci on day 3 and positive Alpha defensin test.
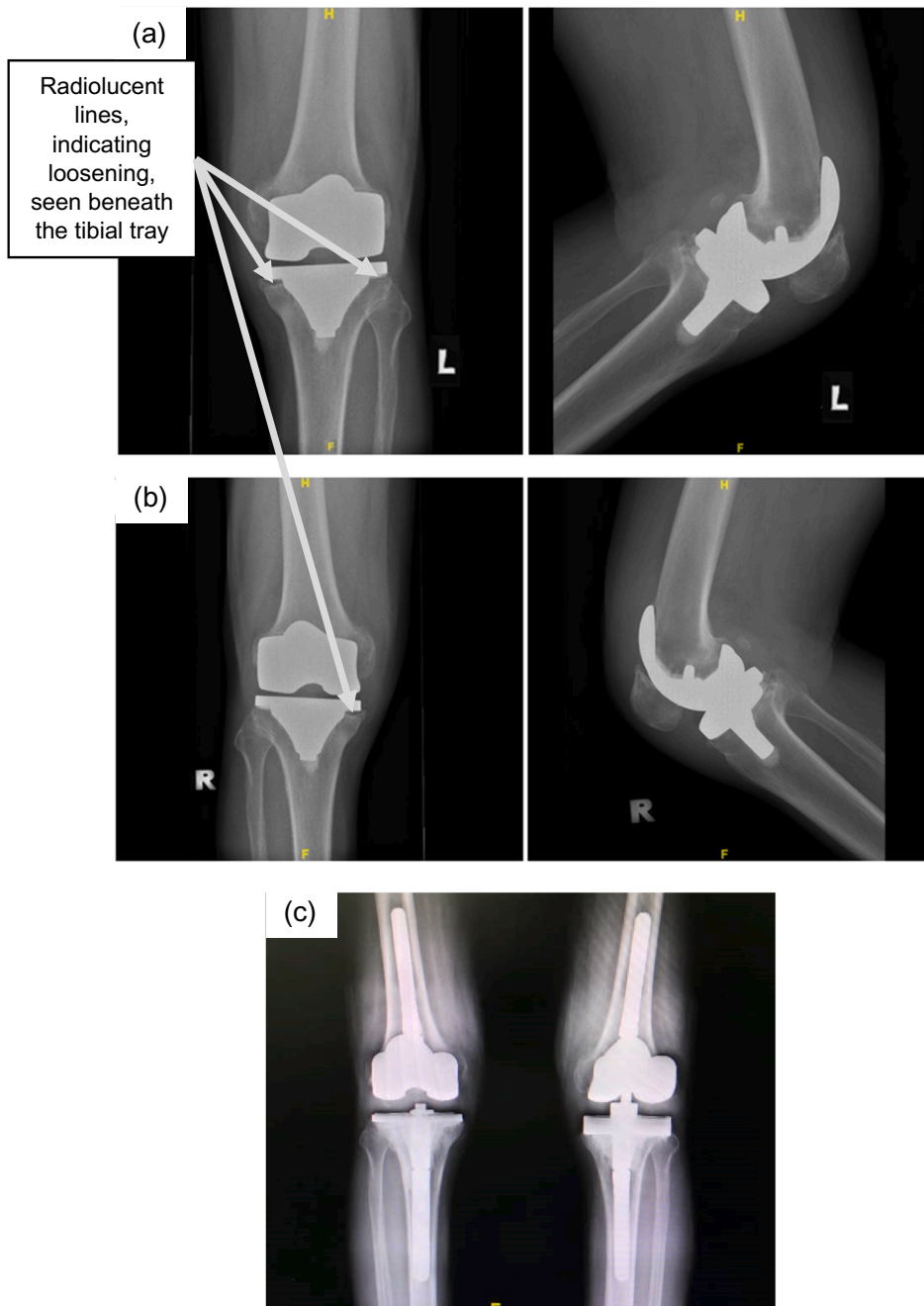
Fig. 1. Anterior and posterior radiographs of (a) left knee of the patient at presentation 6 months after primary total knee replacement (arrow pointing at osteolysis of bone near the implant), (b) right knee at presentation 8 months after primary total knee replacement and anterior radiograph of (c) postoperative view after left and right knee revision knee replacement.

Hence, the patient subsequently underwent right knee first stage revision with insertion of articulating antibiotic cement spacer.

Following completion of antibiotic therapy, the patient underwent staged reimplantation of bilateral knee with condylar constrain implant at 5 weeks and 7 weeks respectively for left and right knee post first stage revision. Oral antibiotic with antibiofilm activity based on culture sensitivity was continued for 5 weeks after 1 week of IV Vancomycin post reimplantation of right knee.

2.1.1. Patient information

The BMI of the patient was $24 \, kg/m^2$, with height of 166 cm and weight of 65.9 kg. Activity level was measured using the Oxford Knee Score (OKS) which assesses the knee pain and function. Besides that, patient reported outcome questionnaire was developed to specifically assess the patient's perspective of outcome following TKR. Each question is scored from 0 (most severe pain or most
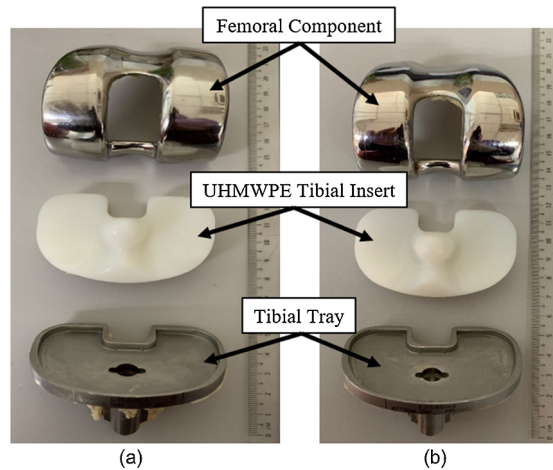
Fig.2. Photo of the knee implant components (a) left (6 months) and right (8 months) after retrieval from the patient (cleaned).

limited function) to 48 (no pain or no function limitation). For this patient, the preoperative and postoperative OKS were 9 and 46, respectively. This indicates that the patient knee pain was relieved and his ability to walk was improved after the revision surgery.

2.1.2. Case 1: Left knee implant

The left knee implant was retrieved 6 months after the primary TKR. The implant is fixed bearing knee implant with cemented femoral and posterior stabilising UHMWPE insert tibial components. The femoral component and the tibial tray were made of cobalt-chromium-molybdenum (CoCrMo) alloy, while the tibial insert was made from highly cross-linked UHMWPE. Patient had the implants removed after following a 1 month duration history of left knee pain and swelling. In Fig. 1a, the preoperative radiography of the left knee shows osteolysis posterior to femoral component and under tibial tray.

2.1.3. Case 2: Right knee implant

The right knee implant was retrieved 8 months after the previous total knee arthroplasty. The implant is fixed bearing knee implant with cemented femoral and posterior stabilising UHMWPE insert tibial components. The femoral component and the tibial tray were made of CoCrMo alloy while the tibial insert was made from highly cross-linked UHMWPE. Periprosthetic joint infection was diagnosed after aspiration of right knee joint fluid.

2.1.4. Postoperative TKR

Both failed knee replacement was replaced with the new implant as shown in Fig. 1c which also indicates restoration of alignment. In Fig. 1c, there is visible different between left and right knee due to different model of knee implant. The right knee is a condylar constrained implant. The left knee has augments to build up the tibial bone loss (thicker tibial insert) and it is a rotating hinge implant. Fig. 2 shows the retrieved knee implant consisting of three components which are femoral component, UHMWPE tibial insert and tibial tray.

After the surgical procedures, the blood on implants were cleaned using water and followed by patting dry with a towel, without rubbing the surface. After dried, the implants were wrapped in surgical towels to prevent scratching or other damage. The wrapped implants were kept in brown paper bag before being handed off to the researchers.

2.2. Surface evaluation

Surface morphology and surface roughness evaluation are done using 3D optical surface profilometer (ZeGage, ZYGO, United States) on both left (6 months) and right (8 months) tibial inserts. Hood's grading scale system is used to analyse the surface roughness and profilometer for both set of insert, where the surface is divided into 10 zones (as shown in Fig. 3). The damage on surface was measure based on extent and severity of seven damage modes (pitting, scratching, burnishing, embedded particulate debris, abrasion, permanent deformation and surface delamination). The analysis of middle part (9, 10) will not be emphasized in this study due to its shape and thus difficult to be analysed. The regions with higher surface roughness obtained from profilometer were further analysed by comparing the features on the samples surface using the electron microscope (JSM-6010PLUS/LV, JEOL, United States).

2.3. Nano-indentation test

The nano-indentation test was conducted to measure the mechanical properties and modulus of elasticity of the UHMWPE tibial insert. The sample was placed on the sample holder of nano-indenter. Indenter with 0.002 N/s loading rate and the maximum
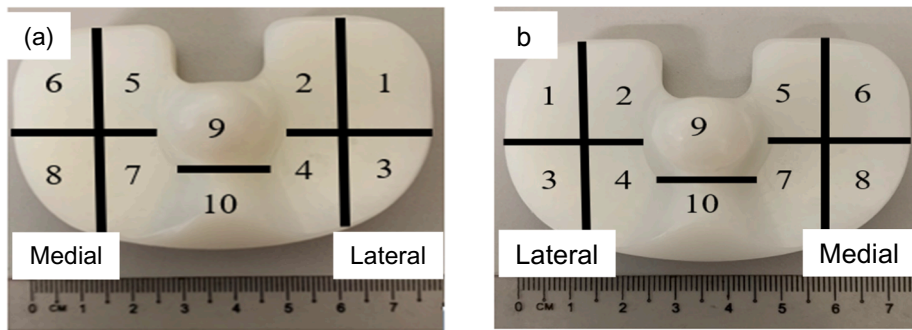
Fig. 3. Schematic shows the 10 zones divided on (a) 6 months; (b) 8 months tibial insert used to characterize damage.

indentation depth of 4 μm is indented onto the sample. The indenter must be hold for 30 s at maximum depth. Average surface hardness was evaluated.

2.4. Oxidation characteristics

The oxidation characteristics of the retrieved knee tibial inserts were analysed using attenuated total reflection-fourier transform infra-red (ATR-FTIR) (Spotlight 200i FTIR Microscope System, PerkinElmer, United States) to analyse the carbon bonding with oxygen molecules. The acquired wavelengths for both bulk and surface area are within intervals $650 \, cm^{-1}$ to $4000 \, cm^{-1}$. The tibial inserts were cut into approximately 1 mm thin section and the FTIR measurements were performed on two distinct regions of the thin section; surface region and bulk region.

2.5. Crystallinity measurements

Crystallinity of UHMWPE were evaluated using Differential Scanning Calorimeter (DSC) (DSC Q20, TA instrument, New Castle). Samples with weight of less than 5 mg were used for the test where they were heated starting from 30 °C to 250 °C at the rate of 10 °C/min. Then the samples were held isothermal at 250 °C for 5 min. Later, the samples were being cooled until 5 °C and was hold isothermal at 5 °C for 5 min. After that, the samples were heated again until 250 °C in order to obtain the total heat of melting, ΔH_m. The percentage of crystallinity was measured by calculating the heat flow of the samples. The measurement of heat flow was obtained during samples heating and cooling processes. The percentage of crystallinity was measured by comparing the ΔH_m to the total heat of fusion, ΔH_f where the ΔH_f of UHMWPE is 293 J/g [17].

2.6. Molecular weight measurements

The molecular weight of the UHMWPE tibial insert was measured by using Gel Permeation Chromatography (GPC) analysis (Waters 2414 refractive index (RI) detector, Gentech Scientific, New York). The test was conducted on a selected region of UHMWPE tibial insert by dissolving the sample in Tetrahydrofuran (THF) at 180 °C.

3. Results

We acknowledge several limitations to this current study. First, there is inadequate information on the patient's medical history. Second, information of implant prior the replacement surgery such as original dimensions and treatment were unavailable. Despite these limitations, this study helps to define damage mechanisms on the surface of revision insert in less than 1 year of implantation. The main focus of this study is to describe the severity and location of damage qualitatively which can discuss the damage mechanism on the early-retrieved implants. In order to examine the severity, graded distinctive surface damage is visualised. After that, it is correlated with mode of damage.

Fig. 4 revealed that both inserts (6 and 8 months) posseses numerous scratch marks oriented in various directions and pits. In this study, most scratching and pitting features present on UHMWPE surfaces can be classified as a wear damage. Early surface analysis indicates that the 6 months old insert had predominantly more wear damage compared to the 8 months old insert. The condition of these surfaces were further analysed by the SEM for better visualization of wear damage.

For SEM observation, it is confirmed that the most common wear damage feature on the articulating surface of both retrieved UHWPE tibal insert was pitting. It is followed by scratches, delamination, ripples as shown in Fig. 5. Pitting of the surface of the 6 months old insert was observed most, followed by scratches and delamination. The surface of 8 months old insert also was dominated by pits, followed by scratches and ripple marks were the least.

In order to confirm the surface incidence of both tibial inserts, the condition of surface was further analysed by comparing surface roughness using 3D microscope. The dimensional surface profile of UHMWPE tibial inserts (Figs. 6 and 7) taken from 3D microscope image have revealed that the wear features in a more specific way. Moreover, surface roughness of the inserts that obtained from the
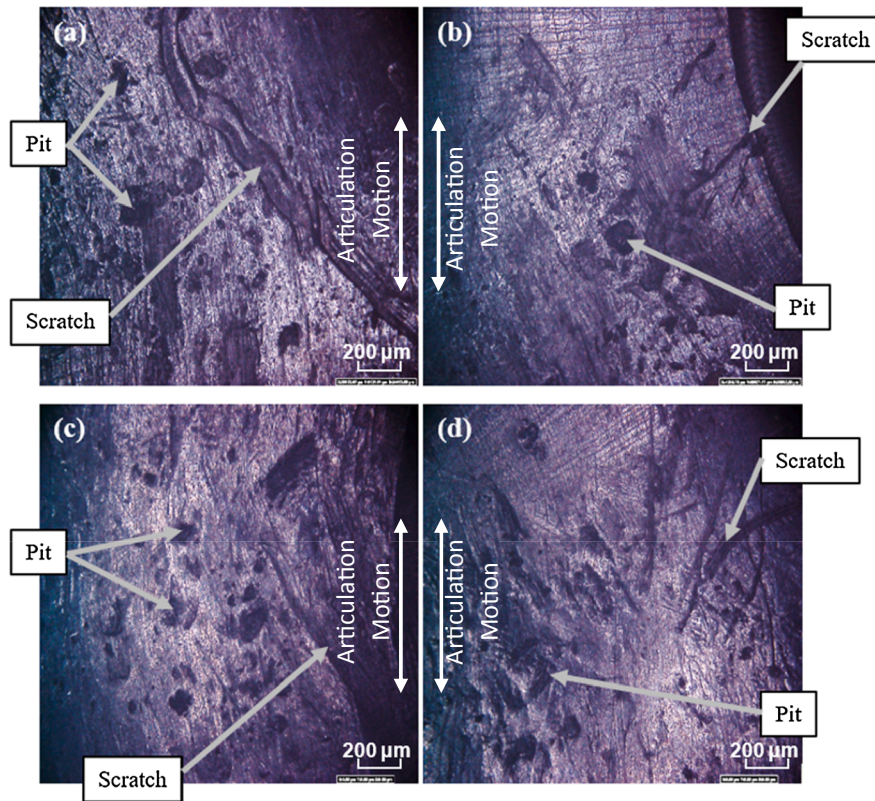
Fig. 4. Optical microscopic image of the surface of 6-month tibial insert (a) lateral; (b) medial compartment; and 8-month tibial insert (c) lateral; (d) medial compartment.

3D microscope have been recorded in Table 1. From Figs. 6 and 7, the pits depth of the 6 months insert in observed more deeper (approximately 27.5 μm) than 8 months insert (approximately 18 μm) and Table 1 results have also shown that the average surface roughness of 6 months insert is higher than 8 months insert. The average roughness of lateral part (2.096 μm) is higher than medial part (1.264 μm) for 6 months insert and the average roughness of lateral part (1.331 μm) is higher than medial part (1.145 μm) for 8 months insert. Rough surface on 6 months insert indicates surface might undergo more wear than 8 months insert (smoother surfaces). The rough surface (4.207 μm) of region 4 at lateral compartment proves that the 6 months insert suffered from high damage.

The hardness and modulus of elasticity of the tibial inserts is recorded in Table 2. The hardness and modulus of elasticity of the retrieved tibial inserts were slightly low compare to the hardness and modulus of elasticity of a new tibial insert [4,18]. Although both of the samples just been employed in patient body for a short implantation time (6 and 8 months). The hardness to modulus of elasticity ratio (H/E) of 6 and 8 months inserts were 20.07×10^{-3} and 20.0×10^{-3}, respectively, which is relatively low for a new UHMWPE insert.

The mechanical degradation of retrieved insert was possibly induced by oxidation. Further analysis on oxidative degradation intervention on retrieved inserts by FTIR was done in order to confirm the possibility occurrence of oxidation. The ATR-FTIR spectra recorded for both 6 and 8 months inserts on surface and bulk region is as shown in Fig. 8. There are several evident peaks recorded at 2918 and 2916 cm^{-1} (C-H stretching), 1460 and 1464 cm^{-1} (C-H bending alkane), 726 and 714 cm^{-1} (C-H bending mono-substituted) due to absorption. Additionally, there are a number of small absorption peaks at surface and bulk regions which can be assigned to oxidation products. These are acids in the range of 1239 to 1264 cm^{-1} and carbonyl group in the range of 1712 to 1729 cm^{-1} [19]. Absorption peaks that indicate the occurrence of oxidation were detected on both surface which proves the inserts undergoes oxidation degradation.

The degree of crystallinity of the early retrieved UHMWPE tibial inserts was evaluated by using DSC to determine its crystallinity percentage. The degree of crystallinity of the inserts is shown in Table 3. There is no much different on crystallinity of the both inserts, the obtaining crystallinity was approximately 53%. Some limitations have been noted about crystallinity assessments because both inserts fall between acceptable medical range, 39% to 75% and there was lack of initial crystallinity percentage recorded of prior to implantation [20]. While the molecular weight (Mw) of the inserts was measured by GPC technique is shown in Table 4. The Mw for 6 months and 8 months was 204, 050 and 254, 010 g/mol, respectively.
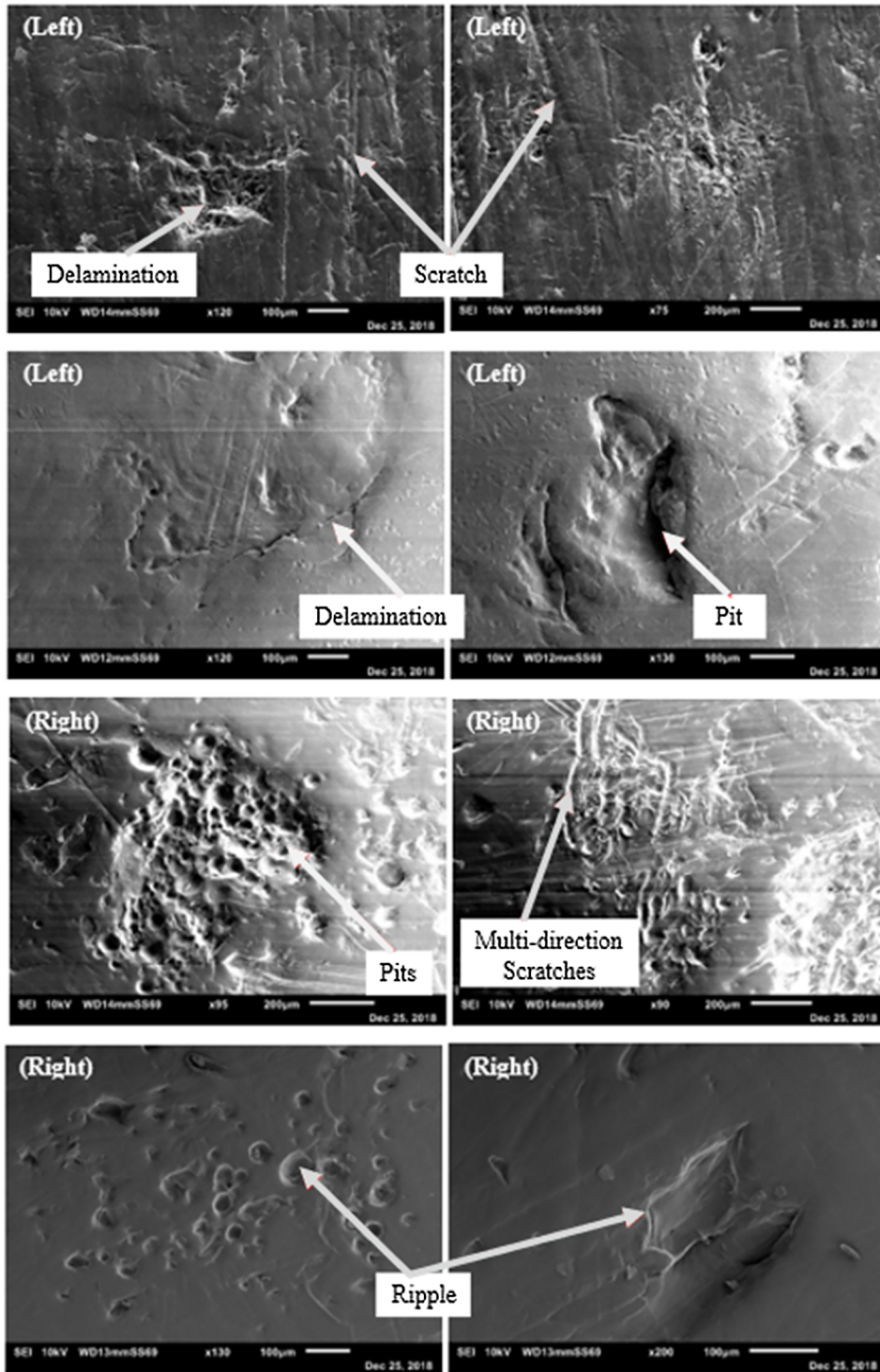
Fig. 5. SEM wear characteristics micrographs on 6 and 8 months UHMWPE tibial insert.

4. Discussion

The predominant reason for revision in both polyethylene inserts is infection and the knee implant failures are not caused by polyethylene wear. Although the cause of the failure was not related to wear, surface analysis was performed to obtain information on surface damage mode for early implanted insert in order to evaluate the early effects of in vivo and provide information to understand
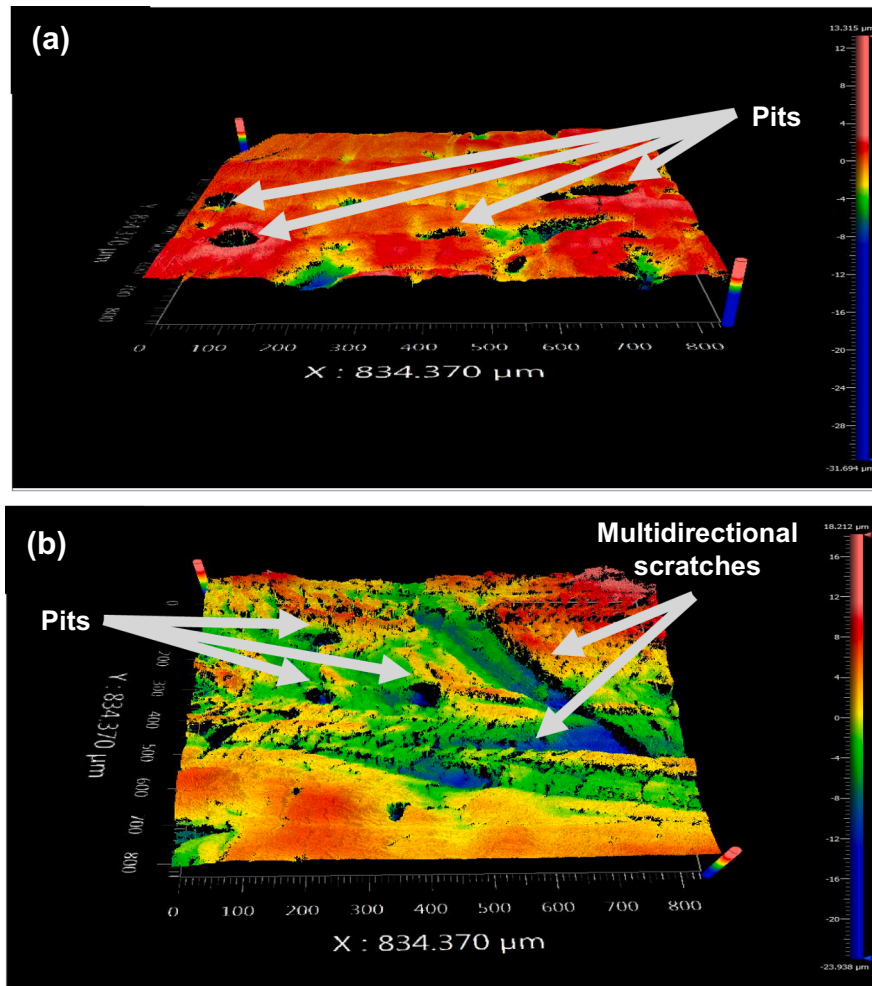
Fig. 6. 3D laser images taken for surface roughness measurement of 6 months UHMWPE tibial insert; (a) medial and (b) lateral compartment.

the evolution of surface feature with longer term in vivo durations for further future investigation.

According to Hood et al. [21], each polyethylene inserts were evaluated for seven damage modes: pitting, scratching, burnishing, embedded particulate debris, abrasion, permanent deformation and surface delamination in detecting damage severity during implantation periods. Visually; pitting and scratching appears more prevalent on both 6 and 8 months inserts. It was also interesting to observe surface delamination for 6 months insert.

A correlation between implantation time and surface damages score was found by Garcia et al. [13]. Greater levels of damage were present with longer in vivo implantation time (from 0.3 to 191.3 months). However, while we anticipated less wear damage from short implantation time (less than 8 months), current study revealed that three from seven main common surface wear damage modes were present on the inserts. The development of pitting, scratching, and surface delamination at this relatively short implantation time may imply that higher prevalence of wear was found. Although the implantation period is very short but based on the identified damage modes, even inserts with short periods of implantation had severe damage and wear. More precisely, according to Ho et al [15], the retrieved sample more likely to achieve the failure state is categorized as high-grade wear which consists at least three modes of surface damage namely pitting, scratching, and delamination. Hence, in present study, retrieved polyethylene inserts with short implantation duration was considered to have high-grade wear modes.

In this study, the form of pitting on the surface appeared to be like indentations and can be suggested that there is significant material loss during the articulation motion of the implant [17]. The loss of material in particulate form is known as third body particles or wear debris. Previous study suggested that pitting and scratching on the articulating surface is initiated by the hard wear debris which entering the articulation and locally deforming the soft UHMWPE surface [17,22]. In addition, wear scratches caused by wear debris where it embeds into the softer surface or rolls or tumbles through the contact, a series of indentations is found which further causes groove formation. Based on this observation, it can be suggesting that the wear features of both inserts indicate the failure mechanism of this case can be characterized as abrasive wear. However, this study is limited by assumptions like the absence of third body wear in order to prove the cause of third bodies for pitting and scratching formation. Scratches found on the surface of
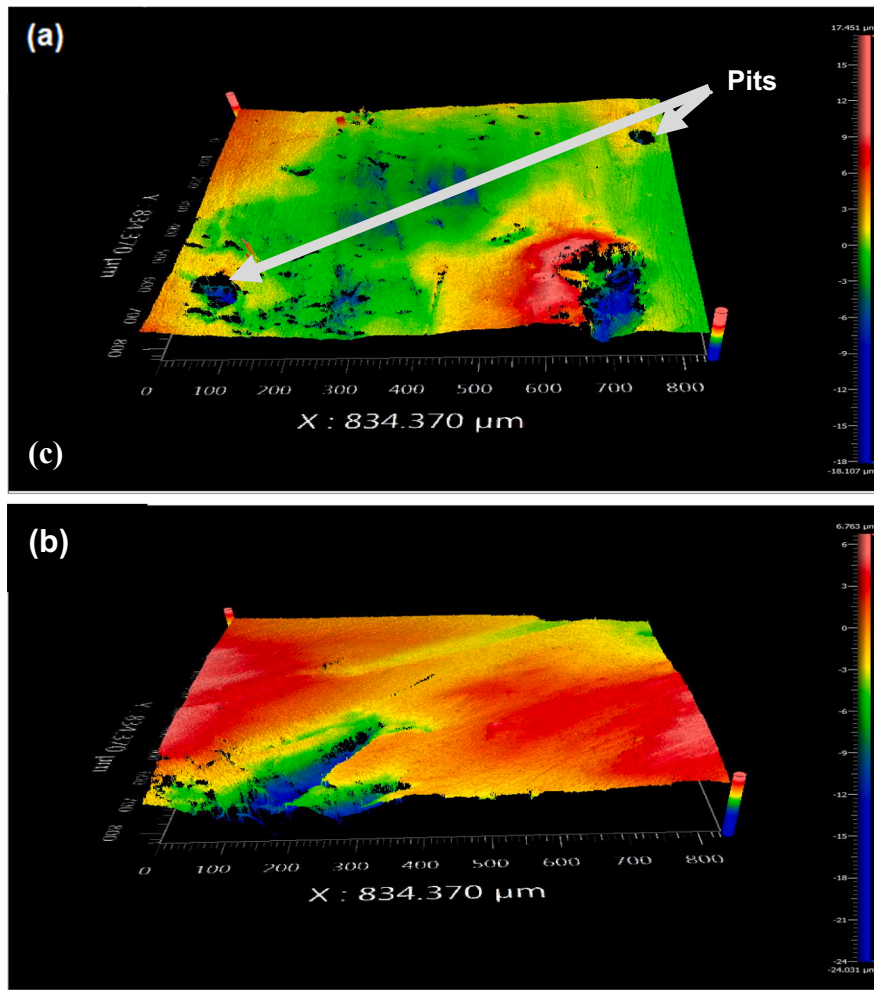
Fig. 7. 3D laser images taken for surface roughness measurement of 8 months UHMWPE tibial insert; (a) medial and (b) lateral compartment.

Table 1
Surface roughness categorized by compartment of 6 and 8 months UHMWPE tibial inserts.

UHMWPE tibial insert	Lateral				Medial				Average [μm]
	1	2	3	4	5	6	7	8	
6 months	1.186	2.120	0.870	4.207	1.254	1.253	1.568	0.980	1.6798
8 months	0.992	1.467	1.498	1.366	1.763	1.243	1.021	0.551	1.2376

Table 2
Hardness and modulus of elasticity of retrieved UHMWPE tibial inserts.

UHMWPE tibial insert	Hardness [MPa]	Modulus of elasticity [GPa]
6 months	28.7	1.43
8 months	29.2	1.46

insert was not originated from surgical retrieval process. We confirmed that the surgeons followed the standard operating procedures (SOPs) for the implant retrieval process including; using an instrument designed for removal of the polyethylene insert from the tibial tray by disengaging the locking mechanism from the polyethylene-tibial tray interface which is located away from the articulating surface (the underside of the polyethylene inserts). The femoral component was loosened from the implant-bone cement interface and this was also not involving the articulating surface of the femoral component.

Many retrieval studies reported surface damage features such as pitting and delamination are often observed in retrieved
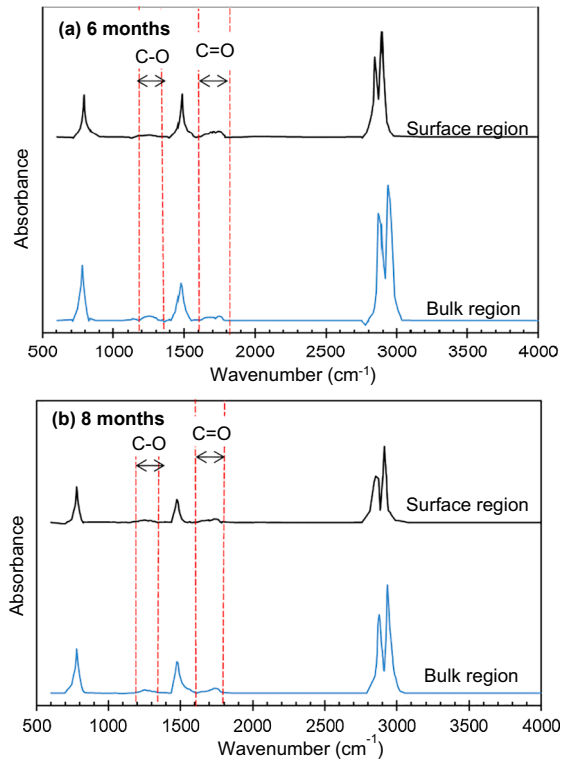
Fig. 8. ATR-FTIR spectra for (a) 6 months; and (b) 8 months retrieved UHMWPE tibial inserts.

Table 3
Degree of crystallization of retrieved UHMWPE tibial inserts.

Sample	Melt Onset Temperature [°C]	Melt peak Temperature [°C]	Enthalpy [J/g]	Crystallinity [%]
6 months	123.0	136.9	157.6	53.79
8 months	120.1	134.0	155.3	53.0

Table 4
Molecular weight of retrieved UHMWPE tibial inserts from GPC analysis.

UHMWPE tibial insert	Elution Volume [ml]	Retenti-on time [min]	Adjust-ed RT [min]	Mn	Mw [g/mol]	MP	Mz	Mz + 1	Mz/Mw
6-month	19.775	19.775	19.775	158,570	204,050	459,100	258,090	306,380	1.2647
8-month	19.727	19.727	19.727	198,410	254,010	479,280	317,647	420,642	1.2505

polyethylene inserts due to fatigue wear [5,13,21–23]. In TKR, fatigue phenomenon usually associated with cyclic stress on the contact area between the insert and femoral component. Because of this, at first we assume an increasing number of cycles will increase in the incidence of pitting and delamination, due to repetitive forces on different axes. For example, Murtaglou et al. [24] reported that during 5 million cycles of simulated normal gait, the conventional polyethylene insert showed large areas of delamination. In contrast to previous study, Flannery et al. [25] reported the fatigue related wear characteristics such as delamination and pitting was not detected on the surface of polyethylene after short simulator wear test. In their study, wear knee simulator tests were carried out under 2200 N for two millions of cycles which considered representative of 2 years' service of the TKR joint. On the other hand, fatigue tests were performed by Villa et al. [26] using different load, 500, 2000 and 4000 N. As expected, fatigue tests on the prostheses at 500 and 2000 N reached five million cycles each without any sign of failure. However, the fatigue test failed at 4000 N after 1.7×10^5 and 3.8×10^5 cycles, respectively. The findings from above studies, explains millions of cycles might be required to cause fatigue wear. In addition, by considering the gait cycle, delamination should not be appeared on the insert at least 5 years of implantation. Study by Zahiri et al. [27] reported that the average walking activity of the men with a total joint prosthesis were about 1.07 million cycles per year. Hence the less of gait cycle indicates there is no effect of fatigue cycle on the formation of delamination in current study.

Although many studies have reported on in vivo degradation of polyethylene insert related to fatigue wear, in vivo oxidation was also ultimately recognized as probably the most important contributor to delamination. In this study, from FTIR analysis confirms

that oxidation degradation had occurred in the both polyethylene inserts. It has long been known that oxidation severely degrades the mechanical properties such as loss of toughness can also lead to a decrement in wear resistance [20,28]. Diabb, J.'s et al. [5] study has reported that there is molecular weight reduction of approximately 88.7% for insert that retrieved after 7 months of TKR which lead severe wear. The common factors for degradation of molecular weight in early-retrieved implant are most likely due to the sterilization process that conduct on the implant. The irradiation that the implants undergoes will cause surface oxidation which then leads to reduction of molecular weight of the inserts [5]. In this study, both 6 and 8 months inserts have undergone approximately 86.4% and 83.1% of weight reduction respectively from the standard medical grade which should be 1.5×10^6 g/mol [20]. The reduction of molecular weight of retrieved both inserts have suggested that polyethylene properties have changed, and the changes are believed to have contribute to the mechanical degradation (low hardness to modulus of elasticity ratio) and ultimately led occurrence of the wear damage.

We should be aware of oxidised insert since it has limited success in dynamic applications, due to the delamination tendencies. The oxidative degradation in early stage of implantation could lead to future fatigue where polyethylene may lose mechanical properties and have the compromised ability to withstand mechanical loading under the repetitive cycles. In the meantime, the early sign of surface damage such pitting and scratching can lead to severe surface damage. Normally the pit growth rate increases as a function of time. For example, in this study we have measure the average size of pit for 6 and 8 months was 27.5 μm and 18 μm, respectively. Pit depth as large as 60 μm was measured on the 10 years implanted polyethylene insert surface [22]. Overtime, the formation of surface damage modes was related to each other, there is possibility that the pit becomes larger and may contributes to development of delamination under the repetitive load cycle. Scratching also could has high potential in producing debris where the wear debris agglomerate aggressively on the surface during sliding can lead to severe surface damage.

Thus, the preliminary study on surface damage mode suggested that evolution of the surface features was more likely to occur with long term in vivo durations. Our analysis shows evidence of surface damage related to oxidation and preventative measures must be taken by the manufacturer and surgeon in order to minimize the oxidative degradation at the early stage of implantation.

5. Conclusion

The following conclusions can be drawn from the present study.

1. The high incidence of micro pits (average depth of 27.5 μm for 6 months insert and 18 μm for 8 months insert) and scratching as the observed surface defects. The main factor that caused these wear features is wear debris that enter during the articulation motion of the implants.
2. 6 months tibial insert is observed to exhibit high-grade wear, while 8 months tibial insert is observed to possessed low-grade wear.
   a. The mode of damage of 6 months tibial insert is being characterise as abrasive wear and oxidation induced wear.
   b. The mode of damage of 8 months tibial insert is being characterise as mild abrasive wear.
3. The reduction of mechanical properties of early retrieved UHMWPE tibial inserts is caused by changes to the molecular weight. It is believed to have contributed to the wear damage. As compared to 8 months tibial insert, 6 months tibial insert undergone approximately 86.4% of weight reduction from the standard medical grade showed the lowest mechanical properties and high-grade wear.

Declaration of Competing Interest

We declare that we have no conflict of interest.

Acknowledgement

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