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Technical note

A novel method to measure rim deformation in UHMWPE acetabular liners

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ABSTRACT

Fluoroscopy studies of total hip replacement (THR) have shown that the femoral head and acetabular cup can separate *in vivo*, causing edge loading on the rim of the cup. Pre-clinical testing of THR involves ISO standard motion and loading parameters that are representative of a standard walking gait. However, a requirement for more robust testing of THR has been identified and protocols for edge loading in hip simulators have been developed. This technical note describes a method to measure rim wear and deformation on ultra-high molecular weight polyethylene acetabular liners using 2D contacting profilometry and Matlab® analysis. The method is demonstrated on liners that have been subjected to edge loading in hip simulator tests and that have been retrieved at revision surgery. A quantitative and qualitative evaluation of the rim deformation was performed with good repeatability using the method.

1. Introduction

Fluoroscopy studies of total hip replacement (THR) have shown that the femoral head and acetabular cup can separate *in vivo*, causing edge loading on the rim of the cup [1–3]. It is thought that this may be caused by sub-optimal component positioning, such as a steeply inclined cup or unmatched centres of rotation of the head and cup, or by joint laxity or lever-out following femoral neck impingement [4–8]. Pre-clinical testing of THR involves ISO standard motion and loading parameters that are representative of a standard walking gait [9]. However, a requirement for more robust testing of THR has been identified [10] and protocols for edge loading in hip simulators have been developed [11].

Rim wear, cracking, fracture and liner dissociation have been reported in retrieved ultra-high molecular weight polyethylene (UHMWPE) acetabular liners and edge loading may be implicated in these failures [12–22]. Edge loading is of particular concern where material degradation or reduced mechanical properties exist, as in the case of oxidised or highly crosslinked UHMWPE [23–26]. Rim damage observed clinically can also be the result of impingement [27,28].

Geometric measurement of acetabular rim deformation may provide important information relating to the prevalence, location, severity and mechanism of *in vivo* rim deformation. This would contribute to our understanding of the effects of edge loading on UHMWPE liners and allows evaluation of the clinical relevance of current simulator edge loading protocols.

Existing geometrical methods to measure wear in acetabular cups often focus on the bearing surface and do not accurately measure geometrical changes high up on the rim or on a chamfered region of the liner [29–32].

This study describes and evaluates a novel method for two dimensional quantitative and qualitative evaluation of rim deformation on UHMWPE acetabular liners.

2. Materials and methods

2.1. Materials

This study measured UHMWPE acetabular liners of one design (Pinnacle®, DePuy Synthes, UK), which comprised a flat horizontal rim region and a chamfered rim region (Fig. 1). The liner was designed to be press fit using a taper lock into a titanium shell with anti-rotation device (ARD) tabs that mated with scallops in the titanium shell at 60° intervals.

The liners had either been hip simulator tested under edge loading conditions for 5Mc (simulator samples), as described in a previous study [11] or were retrieved at revision surgery (explants; NHS Ethical approval 09/H1307/60). Four liners were randomly selected from a larger collection of explants to demonstrate the method. Neutral Pinnacle liners with no visible damage on the horizontal rim were selected. The simulator liners were all 36 mm inner diameter and 56 mm outer diameter and were either cross-linked Marathon® UHMWPE (XLPE) liners or Gamma

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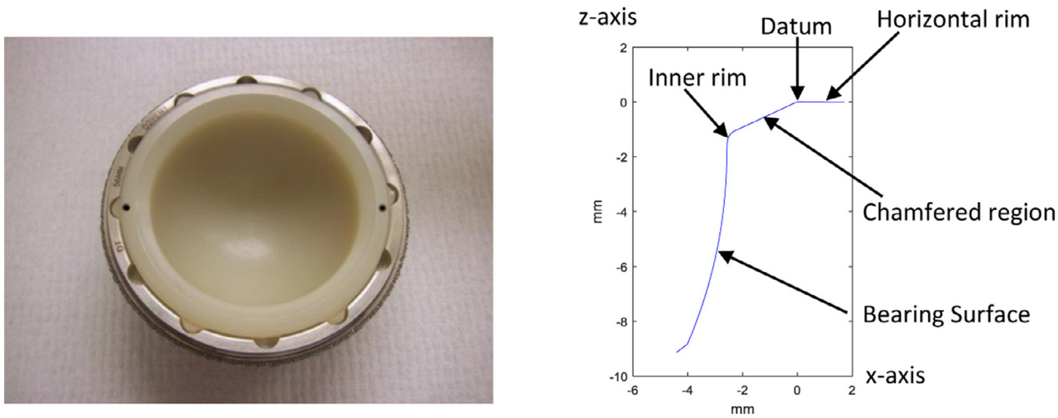

Fig. 1. Image of a 36 mm Pinnacle UHMWPE liner in a titanium shell (left) and a schematic of a cross-sectional unworn rim profile with the nomenclature used in this study (right).

Table 1
Details of the UHMWPE liners that were used to evaluate the rim deformation measurement method.

Sub group	Inner Ø (mm)	Outer Ø (mm)	Material (UHMWPE)	Loading conditions/time *in vivo* (months)	*N*
Control sample XLPE	36	56	XLPE	Untested	1
Simulator sample XLPE	36	56	XLPE	5 million cycles (Mc) of edge loading	4
Simulator sample aged PE	36	56	Aged PE	5Mc edge loading	4
Explanted neutral Pinnacle® Liners	28	Range: 50–56	UHMWPE: crosslinked and non-crosslinked	Time *in vivo* range: 47–101 revised for various reasons	4

Vacuum Foil® UHMWPE liners that had been aged at 70 °C and 75 psi for 14 days in oxygen (aged PE). The explants were various diameters and were either crosslinked or conventional (non-crosslinked) UHMWPE liners. An untested XLPE liner was measured to determine the sensitivity of the method. Summary details of the liners used to evaluate the rim measurement method are provided in Table 1.

2.2. Measurement procedure

Measurements were performed using a contacting profilometer (Talysurf 120L, Taylor Hobson, Leicester, UK) with a 2 µm recessed conical diamond stylus and a contact force of 1 mN. A fixture was designed to allow measurement and alignment of a range of liner diameters, rotation of the liners at 10° intervals and inclination of the liners to 45° (Fig. 2: left). Inclination of the liner prevented 'shanking out' of the stylus when taking measurements. The face of the liner was flush with the fixture so that a 45° angle was maintained when the liner was rotated, preventing tilting of the liner and ensuring a radial trace orientation with respect to the centre of rotation (COR) of the liner. For the simulator samples, five profilometry traces of 9 mm length were taken at 10° intervals across the worn region of the rim (worn traces) and five across the unworn region of the rim (unworn traces; Fig. 2: right). The centre trace on the unworn region of the rim was selected as a reference trace to which all other traces were compared. For the untested liners, the traces were taken in the same way but both regions were unworn. For the explants, where the orientation *in vivo* was unknown, 12 traces at 30° intervals were taken around the circumference of the liner. Data points were taken at intervals of 0.25 µm for all liners. The raw data (x and z coordinates of each trace) were exported for analysis.

2.3. Analysis procedure

A Matlab® (version R2016b, The Mathworks Inc., Natick, MA, USA) code was written to plot and align the traces (worn and unworn) from the acetabular rim and to calculate the rim deformation where edge loading had occurred.

To align the traces, a datum was selected where the horizontal rim met the chamfered region of the liner for all traces (Fig. 3(A)). It was assumed that this datum would have undergone relatively little wear and/or deformation compared to other regions on the worn bearing surface and areas of loading. The datum on each trace was translated to the reference trace and the traces were rotated around the datum to align with the reference trace along the horizontal rim (Fig. 3(B)). All of the traces were then rotated around the datum so that the horizontal rims lay along the horizontal plane (Fig. 3(C)). The rim deformation (penetration) was defined as the distance between the reference trace and a worn trace normal to a tangential unit vector obtained between two points along the reference trace. This was calculated where the mean deformation for all traces was at a maximum between $z = 0$ and $z = \alpha$, where α is to a point defined by the user (Fig. 4(D)).The z cut-off (α) was included to allow the user to exclude areas deemed to be bearing surface rather than rim.

The mean deformation between the reference trace and the five worn traces and the standard deviations were calculated for each sub group. All unworn traces were plotted to visually confirm that the selected reference trace was representative of the unworn rim.

The sensitivity of the method was established using the untested XLPE liner. To do this, each individual trace (all 10 traces) was assigned as the reference trace in turn and the distances to the remaining traces were calculated to create a matrix of rim deformation values. The mean distance between all traces for each reference trace and the standard deviation was then calculated. This was repeated three times, removing and replacing the liner from the fixture, and the mean of all matrices was used to establish the sensitivity of the method. This was done by a single operator.

The measurements of the aged PE simulator samples were performed by two operators and the mean and standard deviations were obtained. Each operator performed the entire measurement protocol, including set-up of the liner and fixture. Intra-class correlation estimates for the two operators were calculated using