Is Linear Penetration an Accurate Surrogate Measure for Volumetric Wear in TKR Tibial Liners?

Elmira Moslemi Rad1, Christopher B. Knowlton2, Robin Pourzal1, Hannah J. Lundberg1, Markus A. Wimmer, Ph.D.1.

1Rush University Medical Center, Chicago, IL, USA, 2University of Illinois at Chicago, Chicago, IL, USA.


Introduction: Long term failure of total knee replacements due to the generation of polyethylene wear debris remains a crucial issue in orthopaedics. Unlike the hip, it is difficult to accurately determine in vivo wear rates. Radiographic methods, where linear wear is defined as joint space narrowing measured on weight bearing patient radiographs, remain the most commonly used methods. However, the complex geometry of contemporary tibial liners poses a challenge for precise radiographic wear assessment leading to inaccurate linear wear measurements [1,2]. In addition, it is not clear how maximum linear penetration translates into volumetric wear loss and particle burden. It was the purpose of this study to retrospectively determine the linear wear penetration and the volumetric wear of tibial liners retrieved after revision surgery or postmortem. It was our hypothesis that the total linear penetration can serve as a good surrogate measure for volumetric wear loss and that both wear rates would correlate with the time in situ.

Methods: For this study, 54 revision or postmortem retrieved UHMWPE NexGen cruciate-retaining tibial liners (Zimmer, Warsaw, IN) with an average time in situ of 5.41±3.13 years were available. Metrology data for the surface of the tibial liners were obtained with a coordinate measuring machine (SmartScope, OGP, Inc., Rochester, NY) using a laser scanner with two micrometers depth accuracy. A total of 400,000 three-dimensional data points were gathered to reconstruct the articular surface of liners utilizing a novel established autonomous mathematical reconstruction method [3]. The maximum linear penetration and the volume loss were calculated and mapped for the lateral and medial side separately for each liner. Areas of visible pitting were removed before quantifying maximum linear penetration. Also, areas of edge deformation confirmed by visual examination were removed before quantifying maximum linear penetration and volume loss.

Both maximum linear penetration and volume loss were plotted versus time in situ for medial, lateral and combined (medial side plus lateral side) sides. Also, the p-values for linear correlations of maximum linear penetration and volume loss over time in situ were computed using student’s t-test.

Results: Wear maps were generated for all components. We found an average combined (medial side plus lateral side) linear penetration of 0.16±0.08 mm/yr. There was a linear relationship between combined penetration and time in situ (R²=0.20, p<0.001) (Fig. 1a). The medial and lateral penetration by itself exhibited lower R² values of 0.096 and 0.103, respectively. For the volume loss, the calculated average total wear rate was 30.72±14.37 mm³/year. There was a significant linear correlation between total wear volume and time in situ (R²=0.45, p<0.001) (Fig. 1b). The lateral volumetric wear rate showed a similar linear relationship (R²= 0.43, p<0.001), whereas the medial volumetric wear rate was slightly lower.
The comparison of the linear and volumetric wear rates demonstrated a good correlation on the medial side with $R^2 = 0.78$ (p<0.001), while the lateral side exhibited a lower $R^2 = 0.41$ (p <0.001). There was a good linear correlation between total volumetric wear rate and combined linear wear rate ($R^2 = 0.61$, p<0.001) (Fig. 2).

**Discussion:** The good correlation between volumetric wear rate and maximum linear penetration rate for the medial and lateral tibial plateau suggests the suitability of maximum linear penetration as a surrogate measure for wear volume, thus confirming our hypothesis. Furthermore, a linear relationship between wear rate and time in situ could be demonstrated. This may come as a surprise since patient weight and activity were unknown and could not be controlled for. Although changes in tibial liner thickness and radiographic TKR joint space narrowing have been utilized in the past for wear estimation, this is the first study to provide evidence for such a procedure using components worn in vivo.

The study has several limitations which should be considered: Only one tibial plateau type has been evaluated. Generalizibility of the results needs to be demonstrated in future investigations. The reconstruction method cannot distinguish between volume loss due to wear and deformation due to creep on the individual liner. However, for the liner cohort, creep estimates are possible. According to our regression model, the maximum linear penetration of 0.51 mm and volume loss of 61.53 mm$^3$ at zero years represent the maximum linear and volume deformation due to creep for the group. In the future, the linear wear rate results of this study will provide a reliable baseline for comparison to radiographic wear measurements.

**Significance:** Quantitative in vivo wear measurements of polyethylene tibial liners will provide input to improve design, materials and longevity of total knee replacements. This study relates volumetric wear and maximum linear penetration on tibial liners to provide the ground work for future TKR in vivo wear analysis.
Figure 2. Correlation of medial, lateral and combined (medial side plus lateral side) volumetric wear rate to maximum linear penetration rate for retrieved tibial inserts for medial, lateral and combined (medial side plus lateral side).