Volume Loss of Retrieved Tibial Inserts Correlates to Visual Damage Score

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INTRODUCTION
Wear of the ultrahigh molecular weight polyethylene (UHMWPE) tibial component can lead to periprosthetic osteolysis, which remains a primary factor limiting the longevity of total knee replacements (TKRs) [1]. Although visual inspection of retrieved tibial inserts can provide invaluable information about in vivo wear mechanisms, only a volume loss analysis can estimate the amount of generated wear debris. Volume loss measurement can help quantify the risk of wear particle-induced osteolysis after revision. This pilot study hypothesizes that visually inspected damage scores will correlate with measured volume loss.

METHODS
This study first verified a method of volume loss analysis using knee-simulator tested components and then applied the method to tibial inserts retrieved after a TKR revision.

Six same-sized GUR 1050 UHMWPE NexGen cruciate-retaining tibial inserts (Zimmer, Warsaw, IN) worn in knee simulator tests were digitized on a FlashScope coordinate measuring machine (OGP, Inc., Rochester, NY) with a low-incidence laser at 2 μm depth accuracy. Each surface scan contained approximately 400,000 three-dimensional data points, limiting the methodological error to ≤ 1 mm³. Components had been worn in three separate level walking gait tests in a four-station knee simulator (Endolab, Rosenheim, Germany) in displacement-control mode per ISO 14243-3 [2]. Autonomous mathematical reconstruction was performed by least-squares fitting a design-congruent curve to the unworn points of each AP line scan and interpolating the original surface in worn regions [3]. Volume loss from the surface was then calculated and mapped. Records of gravimetric mass loss were then converted to volume for comparison, assuming a density of 0.931 mg/mm³ [4].

Nine surgically retrieved UHMWPE Miller-Galante II TKR (Zimmer) tibial inserts of two sizes (n_tibia=5, n_polishing=4) were also scanned. Implantation time ranged from 4.1 to 30.2 months. Three observers independently scored components for deformation/creep, delamination, polishing and pitting, where the final scores were a product of extent and severity averaged across observers. Damage to the medial and lateral tibial plateaus was also scored separately. This study excluded delaminated inserts, postmortem retrievals and inserts with significant edge loading. Scanned inserts were selected from a larger population of retrievals to represent a wide range of total damage scores and patient demographics. Components were reconstructed as before, and volume loss from the articular surface was calculated and mapped. The p-values for linear correlations of volume loss to damage scores were computed.

RESULTS
For knee-simulator worn inserts, calculated volume loss correlated linearly to converted mass loss (p=0.001) as in Fig. 1. Slope of the linear fit was not significantly different from β_M=1 (p=0.36).

Total volume loss correlated to months in situ (2.88+months + 7.12 mm³, p=0.025), which results in wear rates of β_wear=39.2±7.2 mm³/year and β_wear=15.7±2.7 mm³/year (mean ± SE). Figure 2 shows that for each size, total visual damage scores for the entire surface correlated with total volume loss (p_wear=0.001, p_wear=0.0137). Correlation p-values of total, medial and lateral volume losses to their respective total, polishing and pitting damage scores are summarized in Table 1. Reconstruction also allowed for detailed mapping of volume loss on each articular surface, as demonstrated by the visibility of surface pitting in Fig. 3.

DISCUSSION
As demonstrated with simulator-worn components where total mass loss had been measured, autonomous mathematical reconstruction of a scanned insert surface can accurately measure low volume loss. Total damage score and polishing score correlated with volume lost, while pitting score did not. These correlations indicate that polishing damage is the main indicator of volume loss.

Geometric methods cannot distinguish between volume lost to wear and volume lost to deformation and creep, thus volume measurements incorporate both. However, the intercept of the volume-to-mass correlation on simulator-worn components suggests a creep volume of 8.3 mm³. Interestingly, this agrees with the intercept of the volume-to-time in situ correlation for all retrieved components, which suggests a creep volume of 7.1 mm³ at zero months. Damage score correlations also suggest that retrievals experienced damage without volume loss.

The calculated wear rate for all revision retrieved inserts was 34.5 mm³/year. Although higher than reported wear rates from knee simulators [5], it compares favorably to wear rates in retrieved UHMWPE hip replacements with low damage [6]. This implies that TKRs could experience more cross-shear in vivo than in simulator testing, possibly due to various activities of daily living.

SIGNIFICANCE
Volume loss analysis provides surgeons and researchers quantitative information on the risk of osteolysis and TKR contact mechanics, which will ultimately help improve the design and longevity of TKRs.

REFERENCES