Evaluation of New Radiographic Analysis Software in Measuring Polyethylene Wear in Total Knee Arthroplasty

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Disclosures:

Introduction: Wear of polyethylene liners in total knee arthroplasty (TKA) has been linked to a series of negative clinical outcomes, including osteolysis, ligamentous laxity, implant instability, and component misalignment. While the effects of polyethylene wear in TKA have been studied extensively, the prognostic indicators influencing specific wear behaviors are not well understood. Current in vivo wear measurement techniques require fluoroscopic guidance radiographs in order to obtain tangential views of the tibial articular surface. These techniques are time consuming and generally lack sufficient precision to detect clinically relevant wear. Newly available software and imaging technologies may provide a solution to the problem of measuring in vivo polyethylene wear of TKA implants.

The Martell Knee Analysis Suite (KAS, University of Chicago, Chicago, IL) is a specialized program developed to facilitate accurate and repeatable radiographic measurements of TKA implants. Using anteroposterior (AP) and lateral projections of the knee, the program incorporates edge detection software to trace the shape of the implants and user-designated clicks to create three-dimensional femoral and tibial coordinate systems. The program then uses the AP and lateral contours of the components to create a depth map of each femoral condyle in relation to the tibial tray, and measures the distance between the tibial tray and the closest corresponding points of each femoral condyle. The program is designed for use with both beam-centered plain radiographs and the EOS imaging system. EOS utilizes slot-scanning radiography to simultaneously expose AP and lateral projections of the subject without the visual magnification effects of beam-centered radiographs, and can consistently capture clear tangential views of the tibial plane without guidance. The purpose of this study is to evaluate the precision, accuracy, and repeatability of the Martell Knee Analysis Suite software, and to compare the program's performance between simulated plain radiographs, simulated EOS radiographs and phantom EOS radiographs.

Methods: Phase 1: Ten pairs of simulated AP and lateral plain radiographs and ten pairs of simulated AP and lateral EOS radiographs were assembled for a total of 20 film pairs. In both groups, separation of the femoral and tibial components was broken down by film pair at 0, 1, 2, 5, 8, 10, 12, 14, 16, 18, and 20mm. Four readers measured the 20 film pairs three times each for a total of 240 measurements. Minimum separation distance calculated by the program between the femoral and tibial components was recorded for both condyles and compared against the known separation distances. Statistical analysis was performed to assess the accuracy, precision, and repeatability of the Martell software measurements in both simulated radiographic formats.

Phase 2: A phantom knee model was assembled using Stryker Osteonics components and positioned in the center of an EOS machine. An AP and lateral film pair was taken of the knee setup. A strip of Scotch tape, measuring 80 microns in thickness, was then placed on the medial condyle of the femoral component and a second film pair was captured. This process was repeated nine more times until the medial condyle was shimmed up with 10 strips of tape, simulating 10 successive wear intervals of 80 microns in the medial femoral compartment. The tape was then removed and the process was repeated. The two sets of 11 films were then measured by two readers. Minimum separation distance calculated between the medial condyle and the tibial plane was compared against the known change in separation based on the number of tape strips on the femoral component. Statistical analysis was then performed to assess the accuracy, precision, and repeatability of the Martell software measurements in an EOS phantom setup.

Results: Phase 1: Statistical analysis conducted to determine the accuracy and reproducibility of the simulated EOS images produced a root mean square error (RMSE) of 0.875 mm, with a standard error of 0.009mm. Precision of the simulated EOS images was 0.417mm. Analysis of the simulated beam-centered plain radiographs resulted in a RMSE of 1.777mm and a standard error of 0.056mm. Precision of the simulated plain radiographs was 2.518mm. The RMSE of the simulated plain radiographs was over double that of the simulated EOS images, while the standard error and precision values of the simulated plain radiographs were over six times larger than the corresponding simulated EOS values. Despite these results, a student's t-test revealed no significant difference between the wear measurements of the simulated EOS and beam-centered groups (p=0.487).

Phase 2: A similar analysis conducted on the phantom EOS knee measurements revealed a RMSE of 1.401mm, over 1.5 times larger than the simulated EOS images, and a standard error of 0.086mm, nearly 10 times larger than the simulated EOS images. The precision value of the EOS phantom knee images was calculated to be 0.865mm.

Discussion: The negative effects of polyethylene wear on TKA survivorship are well known, however, evaluating the magnitude...
and direction of wear in vivo is difficult to achieve using currently available methods. Our evaluation of the accuracy and precision of the Martell Knee Analysis Suite produced mixed results. The most accurate measurement method was the simulated EOS images (RMSE = 0.875mm), however, a measurement accuracy of 875 microns is likely not sufficient to detect low levels of clinically relevant wear. In contrast, evaluation of the program’s repeatability revealed excellent results, with standard measurement errors ranging from 0.009mm (simulated EOS images) to 0.086mm (phantom EOS images). These numbers suggest that four readers completing repeated measurements of multiple films were able to recreate their measurements from an inter- and intra-reader perspective to a high degree of accuracy. The program also demonstrated sufficient precision levels, ranging from 0.875mm to 2.518mm. While EOS slot-scanning films produced better results than beam-centered radiographs, the substantial difference in performance between simulated EOS and phantom EOS images suggests that suboptimal and changing implant orientation affects a decrease in accuracy, repeatability, and precision.

Our results suggest that the Martell Knee Analysis Suite has potential as a radiographic measurement software given the excellent repeatability and precision of the program, however, more work needs to be done on software measurement algorithms to improve the program’s measurement accuracy before it can be validated for use in clinical studies.

**Significance:** Polyethylene wear in total knee arthroplasty is a well known determinant of unsuccessful clinical outcomes, however, measuring wear in vivo is difficult and thus polyethylene wear behavior is not well understood. This study evaluates a new radiographic analysis software in concert with a new imaging technique that may facilitate accurate and repeatable knee wear measurements.

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**References:**

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