Introduction: Accurate component alignment and soft tissue balancing have been named as two of the most significant factors in successful knee replacement surgery. Component malalignment can lead to abnormal wear, early mechanical loosening and/or patello-femoral related concerns. New techniques utilizing computer assisted navigation during total knee replacement surgery have meant more accurate placement of components. It is hypothesized that more accurate alignment should enhance outcomes with improved function and long term survivorships.

Finite element analysis (FEA) techniques were utilized to verify and quantify this performance improvement. The maximum contact stresses developed in both computer assisted and conventionally aligned knee replacement were compared with an ideally aligned implant. Median and outlier alignment scenarios were examined and contact stresses were compared.

Materials and Methods: Patient data was collected from a randomized prospective study which compared computer-assisted TKR (using the Stryker® Navigation System)(CATKR) and conventional jig based TKR. Post-operative CT scans were used to measure 6 alignment variables (3 for the femoral component and 3 for the tibial component) using the Perth CT Protocol. In Phase 1 of the study, the statistical median alignment value for each of the 6 alignment parameter was computed. Finite element models of components oriented consistent with a median aligned CATKR, a median aligned conventional TKR, and ideally aligned TKR were developed. Finite element analysis was performed to predict maximum contact stresses over 0, 15, 45 and 90° of flexion, with an associated joint compressive force simulating normal activities. In Phase 2, the extreme malalignment for each component alignment parameter from the conventional and computer assisted TKR groups were considered. For each alignment parameter, there were two malalignment extremes (i.e.; a maximally externally rotated and maximally internally rotated femoral component). This resulted in 12 CATKR outlier cases which were compared using FEA with the corresponding 12 conventionally aligned TKA outlier cases at the same 4 flexion angles. The Duracon® Total Knee Replacement, which was used in the original trial, was modeled taking the average size implanted with the thinnest insert. The finite element analysis was performed using solid CAD models of the prostheses and ANSYS v10 (ANSYS Inc., Canonsburg, PA).

Individual finite element models were developed with the components starting in ideal alignment. The components were then rotated to the malaligned positions and into the flexion angles to be studied. Joint compressive forces were applied to the femoral component compressing the target surface into the contact surface elements producing contact area and contact stress results for each alignment and flexion angle scenario.

Results: Phase 1: The median aligned CATKA and conventional TKA maximum contact stresses were compared with an ideally aligned TKA. At full extension, the maximum contact stress of the median conventionally aligned TKA is 17.8% greater than the ideal aligned components, compared to only a 3.5% increase in the median aligned CATKA group. At 15° flexion, the conventional group shows 17.6% increase in maximum contact stress compared to the ideal. The computer assisted group results approached that of the ideal group at this flexion angle. As the knee flexes further to 45 and 90°, both the conventional median aligned group and the computer assisted median aligned group tended towards the ideal.

Phase 2: The individual misalignment extremes for both the conventional and computer assisted groups were generally similar for each alignment variable. Patient-specific compound errors, which represent the summation of individual alignment errors for each patient, were then tabulated for each alignment variable extreme and compared. The average compound error for the conventional aligned outlier cases was 17.9°, compared to only 9.6° for the computer assisted outlier cases.

A comparison was made of the percentage increase in contact stresses for each extreme alignment variable compared to the ideal. On average, over all flexion angles, the conventional outliers generated an increase in maximum contact stresses of 24.7% compared to the ideal. This can be compared to an average maximum contact stress increase of only 12% in the navigated group, averaged over all flexion angles considered.

Discussion: This study demonstrates analytically that, by considering actual patient alignment data, the improved alignment achieved by computer navigation reduces maximum contact stresses in the tibial insert when compared with conventionally aligned prostheses. In the outlier cases, it was also demonstrated that the computer assisted group had a smaller percentage increase in maximum contact stresses from the ideal than the conventional group. This can be explained by the greater compound error seen in the conventional group even though the alignment extremes were similar.