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Outcome Validation of a Simulation based Patient Specific TKA Planning Tool

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Abstract

Dynamic knee computer simulations are a promising surgical planning option in TKA, allowing the impact of plan alterations on joint dynamics to be analysed prior to surgery. Previously, the dynamic results of our simulation have been shown to correlate with outcome; here we show validation of its use in pre-operative planning.

A database of TKA Patients undergoing surgery from 1-Jan-2014 operated on by 9 surgeons, who received a pre-operative and post-operative CT were assessed. A musculoskeletal computational model with similar boundary conditions to the Oxford Knee Rig was used to simulate post-TKA knee dynamics using Adams MSC software (Newport, CA). In addition, a set of pre-operative simulations were generated covering positional variations. The Dynamic Knee Score (DKS), a predictive algorithm machine learned from KOOS scored postoperative cases to predict outcome in preoperative planning was applied to all simulations.

Patients were split into groups depending on whether the 'post-operative achieved position' was the 'best' of the preoperative modelled options in terms of simulated DKS score or not. These results were compared with 12 month postoperative KOOS scores. Cases where the best plan was followed had better outcome results. A relationship was shown with the KOOS Pain subscore, with the portion of patients below a KOOS Pain score of 70 dropping to 11% from 16% (p=0.030) when the best plan was followed.

This study shows significant relationships between selection of patient specific kinematically optimal surgical plan and outcome. Such tools will play an important role in future patient specific decision making.

1. Introduction

Component alignment in Total Knee Arthroplasty (TKA) is one of the drivers of post-operative knee dynamics [1, 2], and through this can influence patient outcome [3]. TKA dynamic outcomes can be

measured in a variety of conventional ways such as gait analysis and video fluoroscopy [4]. Such techniques, however, are all 'after the fact' and are thus not suitable for routine pre-operative planning where variations in the patient specific musculoskeletal environment must be accounted for. Dynamic knee computer simulations are a promising scalable alternative and allow the impact of both patient and surgical factors on joint dynamics and patient outcome to be studied prior to surgery. Previously, the dynamic results of our simulation have been show to correlate with outcome, indicating cases where surgically undesirable dynamic outcomes have led to a reduced patient result [5]. Here we present validation of the use of this tool in preoperative selection of a series of possible alignment plans.

2. Methods

A database of TKA Patients undergoing surgery from 1-Jan-2014 operated on by 9 surgeons, who received a pre-operative and post-operative CT and 12-month post-operative Knee Injury and Osteoarthritis Outcome (KOOS) score were assessed. All knees received either a CR or PS Corin (Raynham, MA) APEX prosthesis. Segmented pre-operative bones, patient specific landmarks and component geometries were registered to the post-operative CT to determine the achieved component placement as per the AURORA protocol [6]. This was termed the 'postoperative achieved position'.

A musculoskeletal computational model with similar boundary conditions to the Oxford Knee Rig developed and validated as described by Theodore et al. [7] was used to simulate post-TKA knee dynamics using Adams MSC software (Newport, CA), see Figure 1. During model generation, anatomic landmarks were recorded to generate patient specific bony axes and define soft-tissue attachment sites. In addition, a set of pre-operative simulations were generated, covering + or -2mm changes to the posterior resection, 0, 6 and 12° targets for tibial slope and rotation of the femur to the trans epicondylar or posterior condylar axis. The Dynamic Knee Score (DKS), a predictive algorithm machine learned from KOOS scored postoperative cases to predict outcome in preoperative planning was applied to all simulations.

Patients were split into groups depending on whether the 'post-operative achieved position' was the 'best' of the preoperative modelled options in terms of simulated DKS score, or a better preoperative plan existed for each of the three sets of preoperative plans (femoral resection, tibial slope, rotation). In the case where the 'post-operative achieved position' was best, the cases were termed as 'best plan followed', while in other cases the surgery had a 'better plan available'. These results were compared with 12-month post-operative KOOS outcome scores, and in each case which of the preoperative simulated positions the post-operative simulation was closest to was assessed.

3. Results

A total of 594 patients were identified in the database. 61% (363) were female and the average age was 69.7 ± 10.1 years.

In general, cases where the best plan was followed had better outcome results. Specific relationships where shown between the planned posterior resection of the femur and frequency of patient reported difficulty straightening (26% vs 15%, p=0.015), difficulty squatting (67% vs 40%, p=0.027) and difficulty kneeling (54% vs 40%, p=0.021), all activities involving flexion of the knee. Pain straightening and bending were also shown to be higher when a better preoperative plan was available for tibial slope. In addition, a general relationship was also shown with the KOOS Symptoms subscore,

with cases in which the best plan was followed reporting a mean score of 84 points vs 79 points (p=0.018).

When considering the rotational alignment scenarios, relationships to outcome existed as well. Patients reporting knee pain at least weekly were 15% when the best rotational plan was followed and 30% otherwise (p=0.007). In addition, a general relationship was also shown with the KOOS Pain subscore, with the portion of patients below a KOOS Pain score of 70 (a Patient Acceptable Symptom State, or PASS [8]) dropping to 11% from 16% (p=0.030) when the best plan was followed. Accounting for a single confounding factor, back pain [9, 10], by removing all those patients with 'extreme' levels of back pain in the analysis, the change was from 16% to 8% below the PASS score (p=0.008), halving the level of indicative dissatisfaction.

4. Discussion

This study has shown statistically significant relationships between a machine learned algorithmic score predictive of outcome and the actual outcome of a patient's surgical procedure. Relationships between component alignment and joint dynamics outcomes have been previously shown to exist [11, 12], however the results of these studies have historically been used to validate surgical references used in aligning components [13]and inform implant design characteristics [14]. Typically, this has been done with reference to kinematic objectives expected to correlate with patient satisfaction or desirable patient outcomes. Here we show the validation of a mechanism for assessing the direct kinematic consequences of a component alignment change within a given patient's specific anatomy and demonstrate how it might guide patient specific decision making in a manner that improves patient outcomes.

5. Conclusion

This study shows statistically significant correlations between selection of patient specific kinematically optimal surgical plan and outcome. Such tools will play an important role in future patient specific decision making.

Figure 1 Computational knee model defined for routine pre-operative planning.

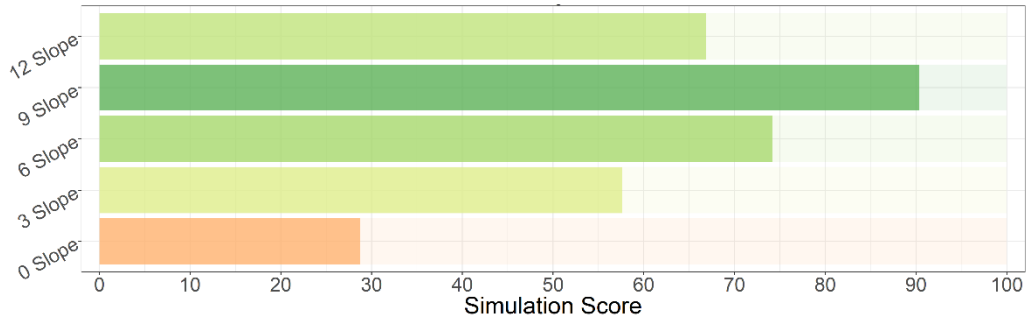

Figure 2. Example of the Dynamic Knee Score predictions. Here 5 preoperative plans exist; the best performing plan was the 9 degree slope plan. If the post-operative achieved position was closest to 9 degrees tibial slope, this would indicate the 'best preoperative plan' was followed, while if it was closer to another slope plan it would indicate the best pre-operative plan was not followed.

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