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Population Level Validation of a Novel Joint Distraction Radiology Protocol in Total Knee Arthroplasty Planning

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Abstract

A key goal of all TKA alignment strategies is to achieve joint balance. This study aims to compare the alignments achieved by preoperatively planning to a novel distracted joint gap protocol to common alignment strategies as well as to the alignment of a healthy non-arthritic population.

A retrospective study comprised of 145 knees was performed. A long-leg supine CT scan, weightbearing AP knee X-ray and two distracted knee X-rays (one each in extension and flexion, making use of an ankle weight to open the joint) were taken pre-operatively. This imaging was used to perform segmentation, landmarking and 3D-to-2D registration. The medial and lateral joint gaps were determined in extension and flexion.

The mean weightbearing, KA planned and distracted joint planned HKA were 4.7° (±5.9°) varus, 0.3° (±3.2°) varus, and 2.2° (±3.5°) varus. This compares to a healthy adult HKA of 1.3° (±2.3°) varus. A patient level comparison between the planned KA and distracted joint HKA found that the coronal angles of the two alignments are within 3° of each other for 64% patients, within 3-5° for 26% of patients and greater than 5° for the remaining 10% of patients.

Of those compared, the planned distracted HKA was the closest to the constitutional varus HKA of a healthy population. Patient level analysis highlighted the fundamental differences between the planned KA and joint distracted alignments. By considering both hard and soft tissue, the planned joint distracted alignment allows for a more holistic foundation for pre-operative surgical planning for a given patient.

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1 Introduction

A key goal of all Total Knee Arthroplasty alignment strategies is to achieve joint balance, which can lead to superior patient outcomes in terms of postoperative satisfaction[1], proprioception[2] and range of motion[3]. Historically this has been achieved by restoring the joint to a neutral mechanical alignment and releasing ligaments, but non-mechanical alternatives such as kinematic alignment approaches are now often practiced. One limitation of these established alignment philosophies is that they are driven by the bony anatomy, with little consideration to the soft-tissue anatomy such as the ligament laxities. Li et al (2022)[4] have previously established that the correctability of a joint cannot be predicted with the bony anatomy alone and that soft tissue laxity is also required. This highlights the need for preoperative analysis of the soft tissue and bony anatomy in order to provide more holistic surgical plans. The authors of this study have developed a novel distracted joint gap imaging and analysis protocol by adapting the imaging protocol introduced by Kanekasu et al (2005)[5], enabling the preoperative capture of ligament laxity information.

This study aims to compare the alignments achieved by pre-operatively planning to this novel distracted joint gap protocol to the functional weightbearing alignment and anatomically referenced Kinematic Alignment (KA) for a given patient population as well as to the alignment of a healthy non-arthritic population as described by Bellemans et al (2012)[6].

2 Methods

A retrospective study comprised of 138 patients totaling 145 operated knees (7 bilateral) was performed. All patients were recruited from a single experienced orthopaedic surgeon between March 2020 and March 2021. A long-leg supine CT scan, weightbearing AP knee X-ray and two distracted knee X-rays (one each in extension and flexion, making use of an ankle weight to open the joint) were taken pre-operatively. Segmentation and landmarking of the CT scans were performed. The output bone models were then registered onto the 3 different X-rays via 3D-to-2D registration, and the medial and lateral joint gaps were determined in extension and flexion. An algorithm corrected for geometrically determined osteophyte tenting of ligaments and a surgical plan to fill the expected gaps formed. Statistical analysis was performed in R Studio v1.3.1903. This retrospective analysis was approved by the Bellberry Human Research Ethics Committee (study number 2012-03-710).

3 Results

The mean patient age was 70.9 ± 8.5 years with 52% (75) female joints. The mean distracted medial and lateral joint gaps were 3.0mm ± 2.2mm and 5.9mm ± 2.0mm in extension and 2.7mm ± 2.1mm and 6.2mm ± 2.2mm in flexion, respectively. After accounting for osteophyte tenting, these medial and lateral joint gaps increased by 0.8mm ± 0.9mm and 0.4mm ± 0.6mm in extension and 1.3mm ± 1.2mm and 0. 7mm ± 1.0mm in flexion, respectively. The mean weightbearing Hip-Knee-Ankle angle (HKA), KA planned HKA and distracted joint planned HKA were 4.7° (±5.9°) varus, 0.3° (±3.2°) varus, and 2.2° (±3.5°) varus. This compares to a healthy adult HKA of 1.3° (±2.3°) varus. A patient level analysis between the planned KA and distracted joint HKA angles found that the coronal angles of the two alignments are within 3° of each other for 64% patients, within 3-5° for 26% of patients and greater than 5° for the remaining 10% of patients.

4 Discussion

The outlined changes in the distracted joint gaps when pre-operatively accounting for osteophyte tenting is comparable to the intraoperative observations of the change in joint gaps with osteophyte removal [7]. A population level analysis displayed that out of the HKA angles analysed, the planned distracted HKA was the closest to the constitutional varus HKA angle of a healthy population[6]. Although the HKA of the kinematic and planned distracted alignments appear to be similar at first, a deeper patient level analysis highlights that the two are ultimately different. Over one-third of patients had a difference of at least 3° between their KA and planned distracted alignment HKA angles, with 10% having a difference of greater than 5°. This highlights the fundamental difference between the two alignments in that the preoperative planning of KA is driven by the bony anatomy alone with limited information about the soft-tissue state, whereas the planned distracted alignment also accounts for the soft-tissue laxity within the joint.

Most current surgical plans aim to either restore the joint to a neutral mechanical alignment or an alignment based on the arthritic state of the joint, both of which often fail to consider information about the soft tissue within the joint, particularly regarding ligament laxity. Considering both hard and soft tissue information, the alignment resulting from the stress radiology protocol discussed in this study allows for a more holistic foundation for pre-operative surgical planning for a given patient.

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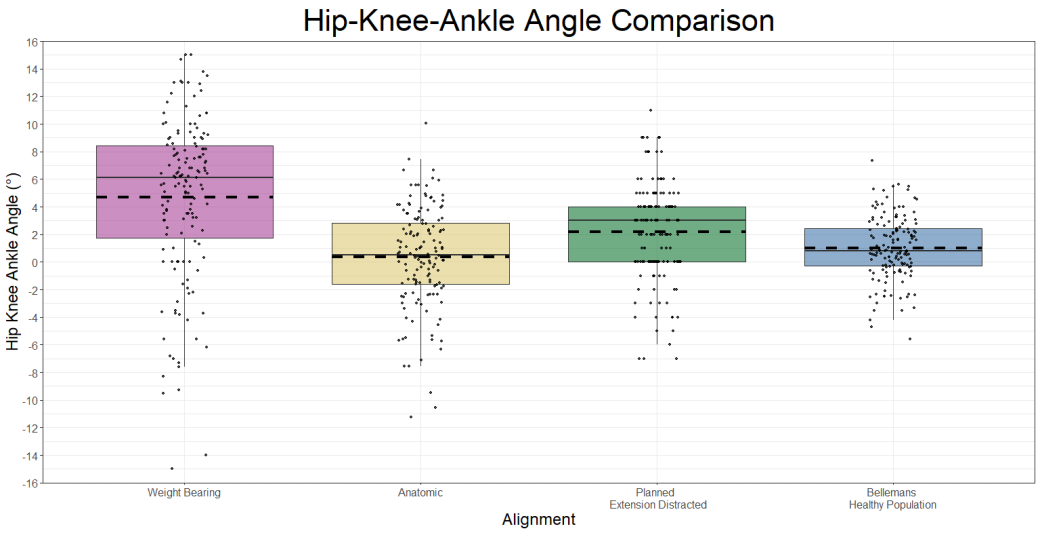

Figure 1. Box plot comparing the weightbearing anatomic and planned distracted HKA of the studied population to each other and to the constitutional varus HKA of a healthy population.

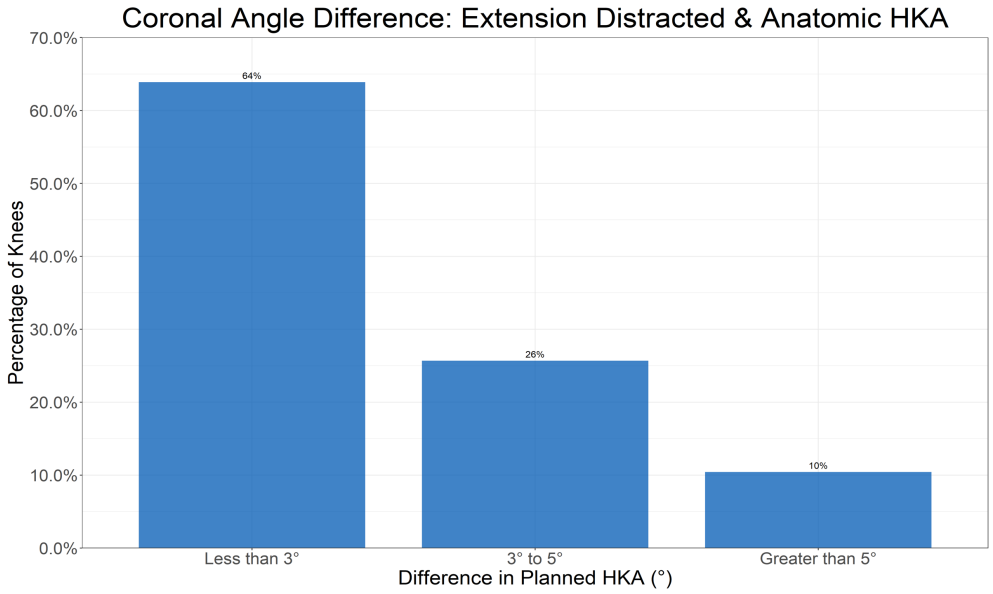

Figure 2. Patient level analysis of the difference in planned extension distracted and anatomic HKA angles. The two HKA are 3 degrees or more different for one-third of the patients assessed.