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A preliminary modeling investigation into the safe correction zone for high tibial osteotomy

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ABSTRACT

Background: High tibial osteotomy (HTO) re-aligns the weight-bearing axis (WBA) of the lower limb. The surgery reduces medial load (reducing pain and slowing progression of cartilage damage) while avoiding overloading the lateral compartment. The optimal correction has not been established. This study investigated how different WBA re-alignments affected load distribution in the knee, to consider the optimal post-surgery re-alignment.
Methods: We collected motion analysis and seven Tesla MRI data from three healthy subjects, and combined this data to create sets of subject-specific finite element models (total = 45 models). Each set of models simulated a range of potential post-HTO knee re-alignments. We shifted the WBA from its native alignment to between 40% and 80% medial–lateral tibial width (corresponding to 2.8°–3.1° varus and 8.5°–9.3° valgus), in three percent increments. We then compared stress/pressure distributions in the models.
Results: Correcting the WBA to 50% tibial width (0° varus–valgus) approximately halved medial compartment stresses, with minimal changes to lateral stress levels, but provided little margin for error in undercorrection. Correcting the WBA to a more commonly-used 62%–65% tibial width (3.4°–4.6° valgus) further reduced medial stresses but introduced the danger of damaging lateral compartment tissues. To balance optimal loading environment with that of the historical risk of under-correction, we propose a new target: WBA correction to 55% tibial width (1.7°–1.9° valgus), which anatomically represented the apex of the lateral tibial spine.
Conclusions: Finite element models can successfully simulate a variety of HTO re-alignments. Correcting the WBA to 55% tibial width (1.7°–1.9° valgus) optimally distributes medial and lateral stresses/pressures.

1. Introduction

Knee osteoarthritis (OA) is a chronic musculoskeletal disease of the tibiofemoral joint, and one of the leading causes of global disability [1]. Evidence suggests that the disease has a mechanical component. For example, approximately 75% of the

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compressive load in the knee passes through the medial compartment [2,3], and 90% of cases of unicompartmental knee OA affect the medial tibiofemoral compartment [4]. Treatments which offload the medial compartment are therefore of great interest.

Opening wedge high tibial osteotomy (HTO) is an established, effective technique used to treat painful isolated medial compartment OA and limb mal-alignment [5–7]. HTO is a particularly attractive option for young individuals, allowing patients to resume high activity levels and delaying the need for arthroplasty [8–10]. The three-dimensional alteration of joint alignment during HTO transfers the position of the weight-bearing axis (WBA) from the affected medial compartment towards or into the normal lateral compartment of the knee (Figure 1). Biomechanically, this lateral shift decreases medial compartment stresses [11,12]. Historically, surgeons aimed to re-align the knee to between three degrees and six degrees valgus [5,13-18]. Re-alignment has also been described according to where the WBA crosses the tibial plateau: as a percentage of tibial width, measured from the medial side. Fugisawa et al. recommend a target zone of 65%–70 %, which has been refined recently to 62.5% (range 62%–66 %) [19,20].

The outcome of HTO deteriorates with time, with around half remaining effective after seven years. The reasons for the unsuccessful outcomes are unclear but are thought to relate to inaccuracies in planning and surgical technique [5,9,14,21]. Despite the widespread use of the procedure, the optimal re-alignment of the WBA of the lower limb remains unknown [22]. A 10 to 13-year follow-up study found that 68 of 93 HTOs were undercorrected and led to continued medial compartment pain, while five of the 93 HTOs were overcorrected, resulting in the onset of lateral compartment pain [23]. Under-correction of pre-operative deformity is an established predictor of failure, while moderate overcorrection appears to be desirable [23,24]. Recent reports suggest that improvements in instrumentation and navigated techniques will improve the accuracy of correction and inherent durability of HTO [25–28]. Understanding the relationship between re-alignment and the resulting stress redistributions will provide insights into future developments in surgical technique [29,30].

We describe the application of finite element (FE) analysis to investigate the relationship between a range of different WBA corrections and the associated stress and pressure distributions on the tibial plateau.

2. Material and methods

Ethical approval (09/H1102/88) for motion analysis was given by National Research Ethics Service (NRES) Committee London – South East. The magnetic resonance imaging (MRI) procedures were performed under an agreed technical development protocol (MSD/IDREC/2010/P17.2) approved by the Oxford University Clinical Trials and Research Governance office, in accordance with the International Electrotechnical Commission and United Kingdom Health Protection Agency guidelines.

2.1. Population information

Motion analysis and MRI data were collected from three healthy subjects: two females, one male; aged 25–32 years; body mass index (BMI) 20.6–21.9; double support standing knee alignments 4.3°–6.6° varus. For this study, the following inclusion

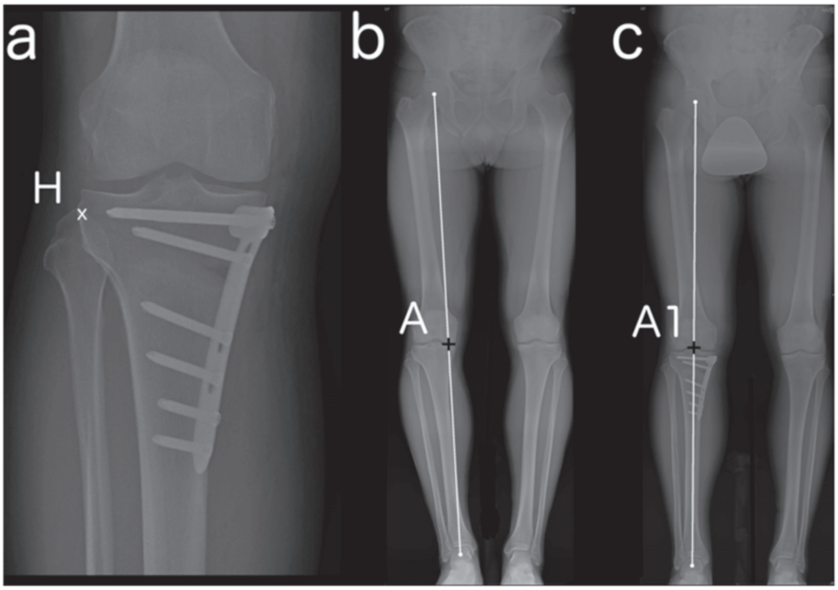

Figure 1. (a) Radiograph of a completed opening wedge HTO using a fixation plate. The osteotomy is made across the tibia and a wedge opened about the hinge point, H. (b, c) This moved the preoperative WBA at the joint line more laterally (as demonstrated by the change from point ‘A’ to ‘A1’).

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