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A low-riding patella in posterior stabilised total knee replacements alters quadriceps' mechanical advantage, resulting in reduced knee flexion moments

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ABSTRACT

Abnormal *in vivo* Total Knee Replacement (TKR) kinetics is influenced by a range of factors, particularly by changes to the knee's geometric parameters such as the patellar tendon moment arm (PTMA). In this study, ground reaction force (GRF) measurements were combined with simultaneous fluoroscopic image measurements to investigate the relationship between abnormal TKR kinetics and geometric parameters. Nine Scorpio Cruciate Retaining (CR) TKR (Stryker, Newbury, UK), nine Scorpio Posterior Stabilized (PS) TKR and seven normal subjects performed a step-up activity on a forceplate in view of a fluoroscope. The TKR subjects were part of a larger ongoing randomised controlled trial. The maximum external knee flexion moment was 22.0% lower in the Scorpio PS group compared to the Scorpio CR group. No significant differences in PTMA were found between the groups. The Scorpio PS had a low-riding patella, with a 30.7% reduction in patellar height compared to the Scorpio CR. This was probably due to using a thick tibial insert after PCL release in the PS, and led to an 8° increase in patellar flexion angle which altered the patellar mechanism and reduced quadriceps' mechanical advantage. Consequently, PS subjects stepped-up more cautiously with a reduced knee flexion moment.

1. Introduction

Problems at the patellofemoral and tibiofemoral joints remain common after Total Knee Replacement (TKR) surgery [1,2]. The causes are relatively unknown, but may be related to abnormal TKR kinetics, such as joint forces and moments [3,4]. Abnormal *in vivo* kinetics after TKR surgery is influenced by a range of interdependent factors. First, TKR surgery may alter important geometric parameters of the knee, such as the patellar tendon moment arm (PTMA) [5]. Second, patients may develop altered muscle strength and joint proprioception, affecting coordination and their ability to generate knee moments [6]. Third, the type of functional activities performed will influence knee kinetics, with more demanding activities likely to exacerbate abnormal kinetics [5]. It remains a challenge for investigators to adequately characterise the relative importance of these factors. In particular, it has been difficult to directly measure important geometric parameters, such as the PTMA, which influence the mechanical advantage of the quadriceps. To better understand the causes of abnormal TKR kinetics, this study focussed on the role of altered geometric parameters.

Both *in vitro* and *in vivo* studies have investigated the mechanical causes of TKR problems [5,7,8]. *In vitro* studies have enabled TKR kinetics and geometric parameters to be measured in a controlled environment, with constant external loading applied to each design. The problem with extrapolating the findings of *in vitro* studies to the patient population is that patients are able to adapt their movement and muscle forces to compensate for changes induced by TKR surgery, such as alterations to the mechanical advantage of the quadriceps [9]. *In vivo* studies, which account for this compensatory behaviour, have identified that various TKR designs produce abnormal kinetics, such as knee flexion moments [5]. However, due to experimental limitations, *in vivo* studies have not adequately explained how abnormal kinetics is related to the TKR's altered geometric parameters [5,10–15].

By simultaneously combining ground reaction force (GRF) and fluoroscopic image measurements, via a simple mathematical model, the relationship between abnormal kinetics and geometric parameters was investigated in a number of TKR groups. In particular, the differences between normal, cruciate retaining (CR) and posterior stabilised (PS) designs were investigated.

This study explored the following null hypotheses:

1. The kinetics and geometric parameters of the Scorpio CR and PS are different to normal.
2. The kinetics and geometric parameters of the Scorpio CR are different to the Scorpio PS.

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2. Method overview

Patients performed a step-up (25 cm) onto a forceplate with their replaced knee in view of a fluoroscope (Fig. 1). A step-up was chosen because it is a demanding activity which requires a large range of motion and generates larger joint forces than level walking [16,17]. It has been used in the past to compare different TKR designs [5,11,18].

The fluoroscopic images were recorded on a digital video recorder and converted into Tagged Image File Format (TIFF) images using Adobe Premiere software (Version 6.0, Adobe Systems Inc., USA). The fluoroscopic images were synchronised with the forceplate data ready for further processing in Matlab (Version 6.1, Mathworks, MA, US). The force data was sampled at 100 Hz, then digitally filtered using a low pass fourth order Butterworth filter with a cut-off frequency of 17 Hz. Force data were then used to calculate the direction and point of application of the ground reaction force (GRF). The fluoroscopic images were corrected for distortion [19,20] and the direct linear transformation (DLT) was used to calibrate the forceplate coordinate system with the fluoroscope's image coordinate system [21]. Further details of the accuracy of this method are included in Appendix A.

To measure knee kinetics, a 2D link-segment model of the foot and shank was used to calculate the net sagittal plane moment about the tibiofemoral contact point. Further details of the model are included in Appendix A. A positive net flexion moment denoted an external sagittal plane moment that tended to flex the knee. Foot and shank segment parameters (mass, position of the centre of mass, and moment of inertia) were defined using anthropometric parameters [22]. The position of the ankle was defined by placing each patient's heel at a fixed location marked on the forceplate, and using anthropometric measurements to define the ankle position relative to the heel. The position of the knee joint was defined as the tibiofemoral contact point. Accelerations of the foot and shank were neglected in the analysis. Error analysis of the link-segment model revealed that neglecting accelerations resulted in less than 2% error in knee joint moments. Furthermore, the effect on knee moments of 10% perturbations of all anthropometric measurements, including ankle position, was investigated, revealing less than 0.3% error.

To characterise the knee's geometric parameters a number of measurements were made. For both TKR and normal groups, the patellar tendon length (PTL) was measured from fluoroscopic images taken at the beginning of the step-up activity with the knee stationary and flexed between 70° and 90°. Patellar height (PH) was also measured in this position, and was defined as the height of the lower pole of the patella above the most distal portion of the femoral component in a TKR (Fig. 2), and above the tibiofemoral contact point in the normal knee [23]. The method to determine the tibiofemoral contact point is described below. These measurements were normalised by shank length.

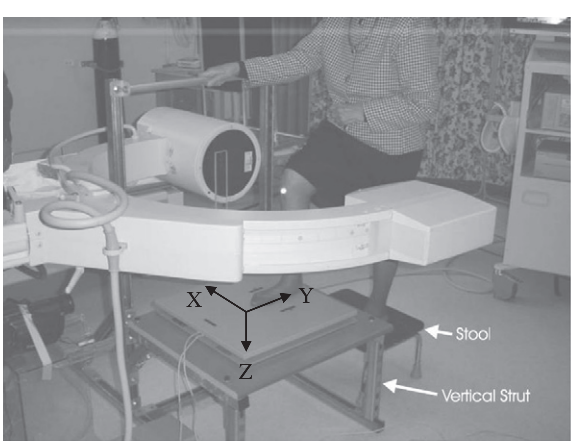

Fig. 1. Patient performing a step-up on a forceplate in view of a fluoroscope.

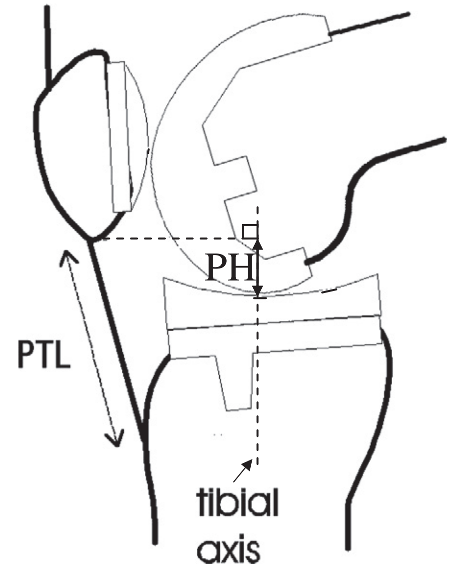

Fig. 2. The patellar tendon length (PTL) and patellar height (PH) were measured in the fluoroscopic images.

Patellar tendon angle (PTA) and patellar flexion angles (PFA) were calculated directly from the fluoroscopic images (Fig. 3). The PTMA was calculated about the tibiofemoral contact point using a variation of the method developed by Kellis et al. [23], in which two circles were fitted to the condyles of the femoral component and a straight line fitted to the tibial plateau near the region of presumed contact. For each condyle, the contact point was defined as the midpoint of the line joining the two closest points on the condyle and tibial plateau. The overall tibiofemoral contact point was defined as the average of the contact points of both condyles.

Step-up times were measured by identifying the start and finish times of the step in the fluoroscopic images. The intra-user and inter-user errors were 0.12 s and 0.14 s, respectively [24].

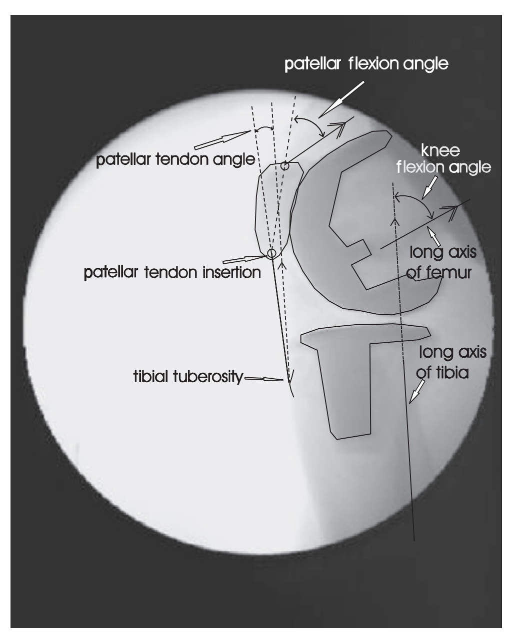

Fig. 3. Determining the patellar tendon angle, patellar flexion angle and knee flexion angle from a fluoroscopic image.