INTRODUCTION

Hundreds of thousands of total knee arthroplasties (TKA) and 22,000 TKA revisions are performed annually in the US alone. While most patients can perform activities of daily living (ADL) following successful recovery from TKA surgery, many experience instability under more stressful conditions [1], and instability is one of the major causes for revision surgery. Clinically, instability in TKA patients is attributed to misalignment or inadequate ligament balancing at surgery, as well as to joint laxity. A common symptom of knee instability is a patient report of the knee “giving way” [2]. Anterior/posterior (A/P) laxity varies considerably between TKA patients. However, research on anterior cruciate ligament (ACL) deficient knees has shown that passive knee laxity is not related to dynamic knee stability [2]. Existing methods of characterizing stability that include only spatial (vs. temporal) aspects are inadequate. Existing temporal methods rely on the periodicity of activities such as gait that are not applicable to non-periodic ADL. In order to explain the lay concept of joint stability with engineering rigor in such activities, new methods of characterization are needed that include temporal parameters that address the transient episodes of “giving way” reported by patients.

A sudden change in muscle forces that causes elevated acceleration and/or jerk can be an indicator of lack of stable control or instability in the underlying structure [3]. The aim of this study was to investigate the use of an inertial measurement unit (IMU) attached at the level of the tibial tuberosity as a tool to evaluate knee stability of TKA patients during ADL.

METHODS

There were 27 patients with unilateral or bilateral TKAs (66±8 years old, 11 males, 38 total TKA knees), and 18 healthy age-matched control subjects (60±6 years old, 7 males, 36 total control knees). An IMU (GLI Interactive LLC, Seattle, WA) set to 100 Hz was used for all testing. It was fixed with a strap over the tibial tuberosity of the subjects. Questionnaires on pain and instability were administered for each subject immediately following the experimental sessions. Both instability and pain were reported as none, mild, or severe in each test activity. All subjects gave informed consent, and experiments were approved by the Institutional Review Board.

Each subject completed five ADLs with the IMU on each leg: (1) walking 3 steps, (2) pivoting towards the test leg, (3) sit to stand, (4) step up/step down, and (5) pivoting opposite the test leg. For each of the five activities, the x (medial/lateral (M/L)), y (A/P), and z (superior/inferior (S/I)) components of linear acceleration were recorded. Ten parameters of interest were identified using a custom MATLAB program - five based on acceleration, and five based on jerk: the maximum, minimum, difference between these (delta), mean, and infinity norm (maximum absolute acceleration) of each trial. The resulting 150 parameters were analyzed statistically to determine which parameters were significantly different between patients and controls [4].

RESULTS

Out of the five activities, the patients reported more instability during Activity 4 – step up and step down – than in any other activity (Figure 1). Additionally, this was the only activity in which any
patient reported severe instability. The patients also reported more pain during Activity 4 than in any other activity. This was also the only activity in which any patient reported severe pain.

![Figure 1: Instability and Pain by activity. All reports were mild except for darker blocks in activity four that indicate severe complaints](image)

There was a statistically significant difference ($p < 0.05$) between groups on 23 parameters as determined by one-way ANOVAs. Of these parameters, 18 depended on components of acceleration in the A/P direction and 5 depended on components in the S/I direction. Six of these parameters were determined in Activity 4 – the activity during which the most pain and instability was reported. Of these 6 metrics, 3 were identifiable from acceleration data alone: the delta, the mean, and the infinity norm. Since Activity 4 involved a step up and a step down procedure, the delta and infinity norm were determined to better characterize the activity than the mean.

**DISCUSSION**

We have demonstrated that IMUs have potential in evaluating instability in patients following TKA surgery. The tests could be readily carried out in a clinical setting, were applicable to several ADL, and results provided a quantifiable indication of instability that correlated with patient-reported instability. The majority of the parameters of interest that showed significant differences between patients and controls were in the A/P direction, which was expected since the main plane of motion in all activities was the sagittal plane. Higher accelerations in patients vs. controls in the activities studied may be due to reduced control of the position of the knee joint. This is consistent with reports of reduced quadriceps muscle strength after TKA which can persist for 1-2 years. This is also seen in ACL deficient patients [5], where instability has been linked to quadriceps weakness.

A limitation of the study is that relative sliding motions between the tibia and the femur could not be characterized by one IMU mounted on the tibia. The study design could not distinguish whether the higher accelerations in TKA patients were due to relative motion of the tibia and femur or resultant motion at the joint. Future work will explore the use of two IMUs (one mounted on the tibia, one mounted on the femur) for better characterization of the relative motion.

**REFERENCES**


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