INTRODUCTION:
Ligamentous structures and articular geometry of the intact natural knee provide stability during a wide range of activities. After total knee replacement (TKR), some patients feel a change in this stability [1]. Several mechanisms contribute to changes in knee laxity after TKR, including implant geometry, alignment, and ligament balance. While laxity at full extension and 90° flexion is balanced through surgical technique, there is little agreement on what constitutes a "well balanced knee" in mid-flexion. The purpose of the current study was to compare the varus-valgus (Vr-Vl) and internal-external (I-E) laxity of healthy knees before and after TKR at full extension and 90° flexion, where balancing was performed, and in knee mid-flexion.

METHODS:
Eight fresh frozen cadaveric knees (M, Age=63±12 years) were evaluated in this experiment. For each cadaver, the proximal end of the femur was mounted rigidly to a surgical table and an analog lower limb, incorporating a 6-DOF load cell (JR3 Inc., Woodland, CA), was mounted to the distal end of the tibia (Fig. 1). Isolated Vr-Vl and I-E torques (+10 N-m and +8 N-m, respectively) were manually applied to the knee at intervals of 5° knee flexion via the analog foot, simulating a clinical laxity assessment. Subsequently, TKR was performed (PFC Sigma, DePuy Inc., Warsaw, IN, USA), with implant alignment and soft tissue balancing performed at the discretion of the surgeon. After TKR, the Vr-Vl and I-E assessments were repeated. The loads and motions at the knee were recorded by the load cell and an Optotruk 3020 camera system (NDI, Waterloo, Canada) and described using a three-cylindrical open chain method [2].

The Vr-Vl and I-E torque-rotation response of the knees were averaged at 0°, 30°, 60°, and 90° knee flexion before and after TKR. A two-way repeated measures ANOVA (TKR, flexion angle) was performed on the peak knee rotations and the peak toe rotations used to determine significant differences. To further quantify the change in knee laxity, polytomous with a "toe-in" region followed by linear knee stiffness (K) were fit to the torque-rotation response of each knee [3]. The mean and standard deviation of knee stiffness was calculated across specimens.

RESULTS:
On average, the natural knee was tightest in full extension for both Vr-Vl and I-E rotations. The overall Vr-Vl ROM increased from 2.6° at full extension to 6.7° at 30° flexion, after which the Vr-Vl ROM remained relatively consistent with increasing knee flexion (Fig. 2). At full extension and 30° flexion, the natural knee was balanced with the overall ROM divided evenly between varus and valgus rotations. At 60° and 90° flexion, there was more varus laxity than valgus. The average I-E ROM significantly increased from 14.0° at full extension to 29.1° at 30° flexion (p<0.00). The overall I-E ROM remained consistent beyond 30° flexion and was evenly distributed between internal and external rotations.

After TKR, the only significant change in knee laxity was an increase in varus rotation at 30° (p<0.03) and 60° (p<0.03) knee flexion (Fig. 2). The increase in rotation was accompanied by a slight decrease in Vr-Vl knee stiffness at all flexion angles (Table 1). There were no significant changes in the Vr-Vl laxity at full extension or at 90° flexion and no change in I-E laxity at any flexion angle.

DISCUSSION:
While ligament balancing procedures strive towards balanced flexion and extension gaps, recent research has noted asymmetry in the laxity of the natural knee in mid and deep flexion [4]. The findings of this study also noted that varus rotation accounted for 59% and 63% of the overall natural Vr-Vl ROM at 60° and 90° knee flexion, respectively. This ratio was consistent after TKR, reinforcing the classical notion of a tight medial condyle with a less constrained lateral condyle. The current study also noted a significant increase in varus laxity after TKR at 30° and 60° knee flexion. Similar studies have reported a 2° increase in Vr-Vl ROM at 20° knee flexion for patients with TKR [5] and an increase in varus laxity in conjunction with a decrease in valgus laxity beyond 30° knee flexion [6]. However, the relationship between knee laxity and the patient’s sense of stability is unknown.

The current experiment had a number of limitations. In particular, the standard deviations of the reported Vr-Vl and I-E laxities after TKR were larger than the standard deviations in the natural knee, which is evidence that surgical technique introduces large variations in laxity. Additional analyses are needed to determine the effect of confounding variables on knee laxity, including implant geometry, implant alignment, and ligament balancing procedures. In addition, there was a lack of muscular contraction, which may contribute to lateral stability. With these results, the fundamental question of optimal knee balance remains. Each of the knees tested in this experiment underwent dynamic weight-bearing simulations of a deep knee bend and a gait cycle in the Kansas Knee Simulator [7]. Future work will focus on understanding the influence of knee laxity on knee kinematics during these activities.

REFERENCES:

AKNOWLEDGEMENTS:
This work was supported in part by DePuy, a Johnson & Johnson company.