BIOMECHANICAL COMPARISON OF ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION TECHNIQUES USING A NOVEL ROBOTICALLY SIMULATED PIVOT SHIFT: A CADAVERIC STUDY

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INTRODUCTION: The robotically simulated clinical pivot shift (PS), a dynamic loading profile based on measurement of loads applied by a surgeon, was developed as a more robust test for detecting kinematic changes for evaluating ACL reconstructions [2]. Two ACL reconstruction techniques were evaluated in this study: the all-epiphyseal (AE) and over-the-top (OTT). These techniques are used exclusively in the pediatric population in lieu of traditional techniques so as not to disrupt the epiphyseal in growing patients. Both techniques’ effectiveness in restoring intact knee kinematics has been examined previously in a cadaveric study, concluding that both techniques provide anterior and rotational stability, but no conclusions were made as to which technique provided more stability [1]. This study aimed to use the simulated clinical PS to assess anterior and rotational stability provided by the AE and OTT surgical techniques.

METHODS: Six fresh-frozen, cadaveric legs were transected mid-femur and mid-tibia and mounted to the Universal Musculoskeletal Simulator capable of real-time force feedback using simVITRO software. Four surgical conditions were tested: Intact knee, deficient ACL, AE reconstruction and OTT reconstruction. The AE and OTT reconstruction order was randomized. For each surgical condition, three tests were performed:

1. Anterior drawer (134 N anterior, 20 N compression) at 0, 15, 30, 60, and 90° of flexion
2. Rotary loads (5 Nm internal rotation torque, 10 Nm valgus torque, 20 N compression) at 5, 15, and 30° of flexion
3. Simulated clinical PS test [2]

For each specimen, the kinematics from the intact knee for each respective test was subtracted from the kinematics of the three remaining surgical conditions to acquire kinematic response relative to the intact knee. Relative anterior tibial translation (ATT) and internal tibial rotation (ITR) were reported at each tested flexion angle for the Anterior Drawer and Rotary Loads tests and for the flexion angle initiating the shift in the simulated clinical PS test. This angle was at the peak ATT and corresponded to the start of the shift. Paired t-tests were used to determine significance (p<0.05). In one specimen the simulated clinical PS could not induce a shift, even in the deficient state, and thus was excluded from the analysis.

RESULTS: Figure 1A displays the ATT and ITR for the simulated clinical PS at the flexion angle initiating the shift. Neither surgery restored intact knee kinematics. OTT exhibited 4.2 mm more ATT compared to AE (p=0.021) and 7.2° more ITR (p=0.015). OTT had no significant kinematic difference compared to the deficient ACL. Figure 1B displays the ATT for the Anterior Drawer test. The AE surgery significantly reduced ATT compared to deficient at flexion angles of 0, 15 and 30°. No significant difference between OTT and deficient was established. Figure 1C and 1D display the ATT and ITR (respectively) for the Rotary Loads test. Neither surgery restored intact knee kinematics nor significantly reduced ATT or ITR compared to the other surgery, agreeing with previous work with similar loading conditions [1].

DISCUSSION: The all-epiphyseal technique, though unable to restore native kinematics, showed significantly improved stability (4.2 mm ATT, 7.2° ITR) compared to the over-the-top technique when tested with a robotically simulated clinical pivot shift. Analysis of the Anterior Drawer and Rotary Loads tests did not detect significant differences in these surgical techniques, and are in agreement with a previous study which utilized similar loading conditions [1]. Limitations of our study include the small sample size, and the removal of one of the specimens. More work is needed on refining the loading profile to ensure it is able to induce a pivot shift in all specimens. While there is still room for improvement, it is currently still more effective than Rotary Loads, especially in its ability to detect rotational instabilities.
The results from our study agree with previous studies [1, 2] in that the Rotary Loads test does not induce large rotational changes amongst ACL surgical states. It also does not provide additional information compared to the Anterior Drawer test for measuring anterior laxity. It is our recommendation that the Rotary Loads test be replaced by the simulated clinical PS when comparing biomechanical advantages of ACL reconstruction techniques in in vitro testing.

SIGNIFICANCE: This study provides evidence that the novel robotically simulated clinical pivot shift is a more robust test for detecting kinematic changes when evaluating ACL reconstructions compared to the traditional Anterior Drawer and Rotary Loads tests. It also provides evidence that the All-Epiphysial technique for reconstructing the ACL restores native kinematics better than the Over-the-Top technique.

REFERENCES:
[1] McCarthy et al., Am J Sports Med. 41,6: 1330-1339,2013
[2] Colbrunn et al., Pro ASME SBC, SCC2013-14288, 2013