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Knee kinematics from ACL rupture to Reconstruction: A cadaveric study

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1. Introduction

The knee stability and mobility is mainly ensured by the good condition of the central pivot i.e. anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) (Flandry et Hommel, 2011). ACL trauma often led to partial or even complete rupture. Complete ACL tear provokes a posterior-anterior translation of the tibia under the femur, as well as an increased external rotation of the knee leading to joint instability (Nakamae et al., 2019). Reconstructive surgery aims to restore knee stability. The aim of this study was to follow the overall process of restoration of the knee kinematics in a cadaveric study.

2. Methods

2.1 Population

The study was conducted on 14 knees from 7 male cadavers, with a mean age of 85 years. Any signs of instability, as well as a history of surgical procedures on the knee or hip joint, constituted exclusion criteria for the cohort. The bodies were frozen and then thawed at room temperature for three hours prior to the start of the experimental procedures, showing no signs of tissue degeneration.

2.2. Materials

The VICON® optoelectronic motion analysis system was used to record the three-dimensional positions of 36 markers. Seven cameras (3 MX-T40, and 4 MX-T20; f=100 Hz), were positioned around the body. Three metal trihedron, each bearing between 3 and 4 infrared-reflective markers (Super-spherical markers, 14 mm, Qualisys®, Sweden), were screwed into the pelvis, femur, and tibia of the lower limbs of the bodies, respectively. In addition, 7 markers were glued on specific anatomical landmarks as the medial and lateral malleoli, medial and lateral epicondyles of the tibia, medial and lateral epicondyles of the femur, and the greater trochanters.

2.3. Procedures

Each body laid out on a dissection table and each knee, following the same order, was tested in 3 anatomical conditions: REF (without any surgical procedure), $\mathbf{ACL}_-$ (damaged ACL), $\mathbf{ACL}_+$ (surgically repaired ACL). The ACL repair was performed by the orthopedic surgeon using a standard suture technique.

Four functional exercises repeated 4 times were manually performed for each knee condition. FLEX100: 100° knee flexion from extended position. ROT30: at 30° knee flexion, maximal lateral-medial ROM. LACHMAN: at 20° knee flexion, plantar sole, flat on the dissection table, before pulling forward the shank. For FLEX100 and ROT30: Flexion/Extension (F/E) ROM, Medial/Lateral rotation (M/L) ROM and Abduction/Adduction (Ab/Ad) ROM were calculated using Euler angles. Maximal displacement tibia-femur was calculated for FLEX100, ROT30, and LACHMAN. One-way ANOVAs were performed to determine whether knee condition influenced the ROM

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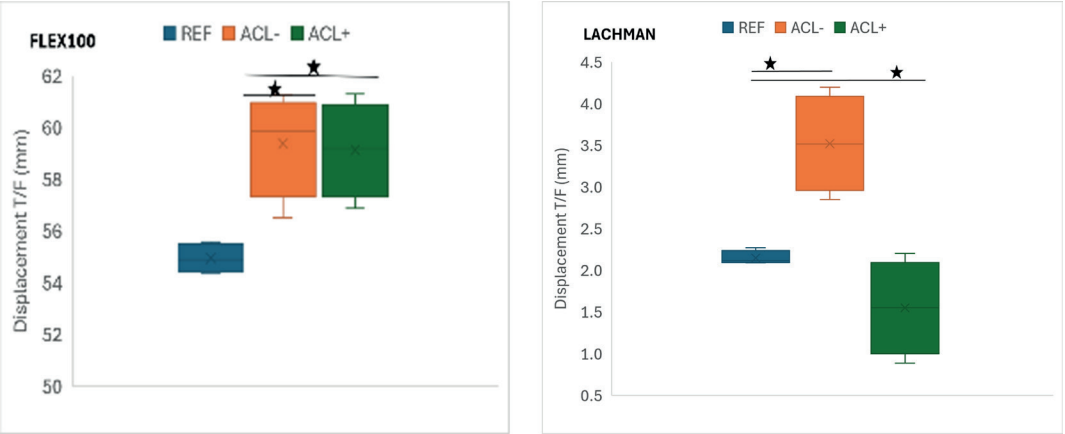

Figure1. Comparison between Reference (REF), ACL damaged (ACL-) and repaired (ACL+) for FLEX100 test (left) and LACHMAN (right).

in each functional exercise with p-value set inferior to 0.05. Tukey post-hoc tests were then performed to compare knee conditions in pairs.

3. Results and discussion

These findings highlighted the critical role of ACL in preserving mobility and stability in the knee joint. Surgical ACL reconstruction was hypothesized to restore the kinematics of the knee joint. We partially validated the hypothesis.

Confirming biomechanical studies (Flandry & Homel, 2011) the ROM of F/E, tibia/femur displacement ($p<0.05$), M/L and, Ab/Ad rotation ($p<1.10^{-4}$) increased between REF and ACL- during the FLEX100. Specifically, there was an increase of 6.6 ± 1.7° in F/E, 1.5 ± 0.1° in Ab/Ad, 11.0 ±0.1° in M/L rotation, and 0.9 ± 3.4 mm in tibial displacement relative to the femur.

In contrast, regarding ROT30, no significant difference was observed between REF and ACL- for the ROM of F/E, Ab/Ad, and tibia/femur displacement. An increase of 4.6 ±0.7 was noted for M/L rotation as for the LACHMAN exercise (1.4 ± 0.2 mm, $p<1.10^{-4}$) (Figure 1).

As expected, the comparison REF and ACL+ during the FLEX100 exercise showed no significant difference of the ROM of F/E, Ab/Ad, and M/L rotation. The larger tibia/femur displacement following AC reattachment (Figure1) can be explained by the characteristics of cadaveric joint tissues, such as a cartilage limited resistance to compression and loss of tensile strength in ligaments and joint capsules (Kiapour et al., 2014). In contrast, a difference of -2.2 ± 2.9 mm was observed for the tibia-femur displacement ($p<1.10^{-4}$) reflecting to a better joint contact. Regarding the ROT30 exercise, no significant difference was observed for the F/E and Ab/Ad ROM. However, an increase of 3.7 ± 0.2 ($p<0.05$) in the M/L rotation amplitude and of 1.0 ± 0.0 mm ($p<1.10^{-4}$) in the tibia-femur displacement was noted. Compared to the Lachman test, an increase of 1.8 ±0.1 mm was observed between REF and ACL+ ($p<1.10^{-4}$). Our results confirmed previous studies showing that ACL reconstruction techniques do not fully restore normal physiology of the movement (Georgiopoulis et al., 2010). In particular, excessive tibial rotation is still reported in high demanding activities (Georgiopoulis et al., 2010). These abnormal biomechanical patterns can place stress on cartilage in areas that are not normally strained in a healthy knee, which can lead to osteoarthritis.

4. Conclusion

This study examined the effects of ACL mechanical repair from the perspective of knee kinematics. If cadaveric studies provide a standard framework in which to conduct robust parametric studies methodological limitations should be addressed due to altered mechanical properties of tissues. Furthermore, given that medial meniscus injury often plays a key role in the biomechanics of the knee joint, its condition (damaged or repaired) should be considered in our future analyses.

Contributor Roles

PC: Conceptualization, Methodology, Writing original draft; TC: Programming, supervising analyses, reviewing; QL: data analysis, statistics; MO surgical supervision.

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