Point-of-Care Motion Capture and Advanced Statistical Modeling as a Biomarker for Return-to-Sport Readiness following ACL Reconstruction

Authors: [1]Ryan T Halvorson, [1]Aidan Foley, [1]Hayden Sampson, [1]Drew Lansdown, [1]Brian Feeley, [1]Jeannie F Bailey
Affiliations: 1. University of California San Francisco, Department of Orthopaedic Surgery

DISCLOSURES: The authors have no relevant disclosures to this analysis.

INTRODUCTION: Few objective biomarkers exist to guide return-to-sport following anterior cruciate ligament reconstruction (ACLR). The ACL Return to Sport Index (ACL-RSI) has been proposed, which gauges patients' psychological readiness for return to sport. However, prior studies have not demonstrated a correlation between ACL-RSI and biomechanical function (O'Connor 2020, AJSM). Point-of-care markerless motion capture combined with advanced statistical modeling holds promise for objective and accurate assessment of biomechanical function and have demonstrated discriminative validity for other orthopaedic conditions (Halvorson 2022, PLOS Digital Health). The purpose of this study was to assess the clinical validity of two biomechanical biomarkers – the Kinematic Deviation Index (KDI) and the Star Excursion Balance Test Functional Workspace (SEBT-FW) – derived from point-of-care motion capture. We hypothesized that KDI and SEBT-FW would improve postoperatively, and would correlate with patient readiness and symptoms at nine months.

METHODS: Adult patients undergoing routine follow up for primary ACLR were eligible for inclusion in this institutional review board approved prospective cohort study. During clinic visits, patients were recorded perform the SEBT, which involves balancing on one leg while reaching with the other leg in a star-shaped pattern, using a markerless motion capture system. KDI was calculated from the results of a three-dimensional statistical shape modeling protocol to assess posture deviation from an "ideal motion trajectory" (Figure 1). SEBT-FW was calculated as the total area in the floor plane covered during the assessment (Figure 1). Patient symptoms were assessed using the Knee Injury and Osteoarthritis Outcome Score (KOOS) and psychological readiness was assessed using ACL-RSI. Temporal trends in outcomes were assess using Kruskall-Wallace tests. Correlation between outcomes was assessed using Spearman's rho.

RESULTS: 43 patients undergoing primary ACLR were recruited (age 34.1; 42% female; BMI 25.6) during routine postoperative follow up (Table 1). Postoperatively, ACL-RSI improved from mean 49.1 (SD 25.5) at 3-6 month follow up to 64.7 (25.2) at 9 month follow up ($p = 0.0026$, Figure 2). KOOS improved from 72.1 (12.2) to 81.8 (11.8) ($p < 0.001$, Figure 2). KDI improved from 1.63 (0.54) to 1.27 (0.39) at 9 month follow up, indicating a trend towards the ideal motion trajectory ($p = 0.0046$, Figure 3). SEBT-FW improved from 0.8 m^2 (0.4) to 1.1 m^2 (0.5) when balancing on the surgical limb ($p = 0.048$, Figure 3). No differences were observed in the contralateral limb for either KDI or SEBT-FW. At 9 month follow up, there was a trend towards correlation between SEBT-FW and ACL-RSI (rho 0.46, $p = 0.07$) and also KDI and KOOS (rho 0.46, $p = 0.10$) but these differences were not statistically significant.

CONCLUSION: This prospective cohort study assessed the clinical validity of two biomechanical biomarkers, KDI and SEBT-FW, derived from point-of-care motion capture, in patients undergoing ACLR. Postoperative improvements were observed in KDI and SEBT-FW, in parallel with subjective improvements in psychological readiness and knee symptoms, as assessed by ACL-RSI and KOOS. Although correlations were observed at 9 month follow up for SEBT-FW and ACL-RSI, as well as between KDI and KOOS, these correlations did not reach statistical significance likely due to our small sample size.

SIGNIFICANCE/CLINICAL RELEVANCE: These findings suggest KDI and SEBT-FW hold potential as objective motion biomarkers following ACLR, but further research with larger sample sizes is warranted to establish their clinical utility and clarify their relationships with psychological readiness and patient symptoms.

Figure 1. Calculation of SEBT-FW (Left) and KDI (Right)

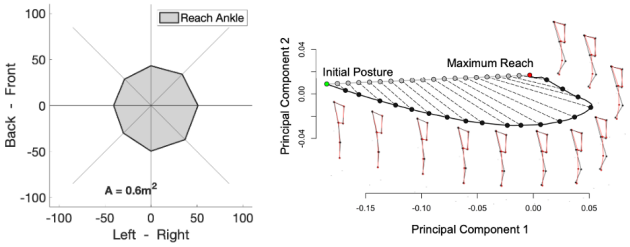

Figure 2. Postoperative Improvement in KDI of Injured and Uninjured limbs

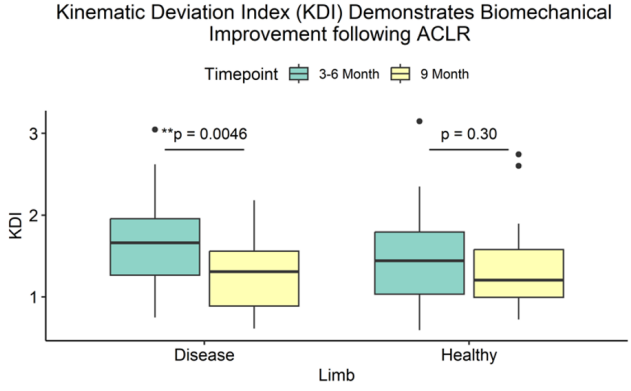

Figure 3. Postoperative Improvement in SEBT-FW of Injured and Uninjured limbs