The Association Between Gait Biomechanical Profile Clusters and Patient-Reported Outcomes at 6 Months Following an Anterior Cruciate Ligament Reconstruction

[1]Erin Carico, [1]Elizabeth Bjornsen, [1]Caroline Lisee, [2]Elizabeth Keiffer, [1]Brian Pietrosimone

[1]University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

[2]University of Arkansas, Fayetteville, Arkansas

BACKGROUND

- PROs are essential for monitoring recovery and the efficiency of an intervention and assessing quality of life (QOL) following joint injury.[1]
- Roughly 43% of patients continue to report clinically relevant knee-related symptoms at 2 years following Anterior Cruciate Ligament Reconstruction (ACLR), and the occurrence of knee-related symptoms at the 6-year follow-up exam is comparable to the 2-year follow-up exam (i.e., 39%)[2]
- Research has found non-modifiable risk factors at the time of injury such as female sex, greater BMI, and greater age at the time of ACL injury to be associated with worse patient-reported outcomes (PROs).[3,4]
- Mechanobiological factors such as poor gait biomechanics, poor cartilage composition, and low physical activity rates have been liked to worsened PROs. [3-5]
- All factors have been assessed in isolation or in small groups; however, it is unknown which factors best identify subgroups of ACLR patients with unique clinical needs.. [6]

PURPOSE

Statement: The study purpose was to (1) identify subgroups of ACLR subjects within a longitudinal cohort that exhibit similar characteristics and (2) determine between-group differences in PROs at 6 months based on identified subgroups.

Hypothesis: We hypothesized physical activity data would be the most predictive in identifying subgroups at risk for worst patient-reported outcomes at six-month post-operation.

METHODS

- Participants aged 16 through 32 underwent a unilateral patellar tendon or hamstring autograft ACLR.
- We performed a cross-sectional study using all available data from a larger longitudinal cohort study. Physical activity, gait biomechanics, patient-reported outcomes, isometric strength, and patient demographic data were collected at preoperative, 2-,4-, and 6 months post-ACLR. MRI data was collected preoperatively.
- Physical Activity: Subjects were instructed to wear a GT9X Link ActiGraph activity monitor on their right hip for 7 days at each time point. A valid wear period was identified as 3 weekdays and 1 weekend day, worn for at least 10 hours each day.
- Gait Biomechanics: An 8 camera, 3D motion capture system (Qualisys, Goteborg, Sweden) collected marker trajectories and participants walked over 2 embedded force plates (Bertec, Columbus OH). Kinetic and kinematic data were sampled at 1200Hz and 120Hz respectively and low-pass filtered at 10Hz (4^{th} order recursive Butterworth). Biomechanical variables of interest included vertical ground reaction force (vGRF), knee flexion angle (KFA), knee extension moment (KEM), and knee abduction moment for the ACLR and uninvolved limbs.
- Patient-Reported Outcomes: Subjects completed self-reported questionnaires including Knee Injury and Osteoarthritis Outcome Score (KOOS), International Knee Documentation Committee Score (IKDC), Marx Activity Rating Scale, and Tenger Activity scale at each time point.
- Strength: Subjects sat in a Dynameter and isometrically contracted their quadriceps, their Maximum Voluntary Isometric Contraction value was recorded in both limbs.
- MRI-Estimated Cartilage Composition: T1rho relaxation times were collected bilaterally preoperatively. T1ρ relaxation times were calculated for the tibiofemoral articular cartilage of the weight-bearing medial and lateral tibial and femoral condyles.

Statistical Analysis

- Standardized data was used to group participants into clusters using a K-Means cluster using the Cluster Analysis function in SAS Enterprise Guide (mean = 0, SD =1) with full seed replacement
- Clusters were formed for each subset of data as well as the dataset as a whole (k=2,3,4) and the number of clusters was determined from the Pseudo F statistic and Cubic Clustering Criterion
- For the best model selected, we will report the top ten variables that contributed most to the formation of the clusters
- Independent t-tests were utilized to determine between-group differences in the KOOS subscales (QOL, ADL, Sport and Rec, Pain, and Symptoms) at the six-month post-operative timepoint.

RESULTS

	Variable	% of Univariate Variance Explained	Cluster 1 (Higher Force)	Cluster 2 (Lower Force)
Involved limb	Vertical Ground Reaction Force Midstance Minimum	40.8 - 6 month	0.777 ± 0.039	0.837 ± 0.036
	Peak Vertical Ground Reaction Force in the first 50% of stance phase	40.7 - 6 month	1.088 ± 0.061	1.012 ± 0.034
	Vertical Ground Reaction Force Impulse	40.6 - 6 month	645.565 ± 26.56	684.483 ± 22.52
	Knee Extension Moment	34.5 - Pre-Op	-0.021 ± 0.012	-0.017 ± 0.007
Uninvolved Limb	Knee Extension Impulse	37.7 - Pre-Op	-0.025 ± 0.014	-0.021 ± 0.010
		43.9 - 4 month	-0.027 ± 0.015	-0.022 ± 0.012
	Vertical Ground Reaction Force Midstance Minimum	42.4 - 6 month	0.749 ±0.046	0.818 ± 0.037
	Knee Extension Moment	36.5 - Pre-Op	2.11 ± 7.30	2.87 ± 6.11
		39.6 - 4 month	1.061 ± 5.85	2.575 ± 4.89
	Peak Vertical Ground Reaction Force in the first 50% of stance phase	34.6 - 4 month	1.114 ± 0.066	1.032 ± 0.045

Table 1: Ten most influential variables, percent variance explained, and mean and standard deviation values for each of the variables per cluster

Primary Analysis:

- The cohort was best separated into two clusters (Pseudo F=6.91; CCC=8.571).
- Out of all data available, gait biomechanical outcomes, specifically vGRF variables, were most influential in separating the cohort in two clusters.
- Cluster 2 demonstrated worse discrete vGRF metrics in the involved and uninvolved limbs, including lower peak vGRF, greater midstance vGRF and greater vGRF impulse.

Secondary Analysis:

- A single outlier was removed from the secondary analysis (>3SD).
- No statistically significant differences in the KOOS subscales were observed between groups.
- QOL – p = 0.74, ADL – p = 0.30, Sport and Rec – p = 0.99 Pain – p = 0.25, and Symptoms – p = 0.41

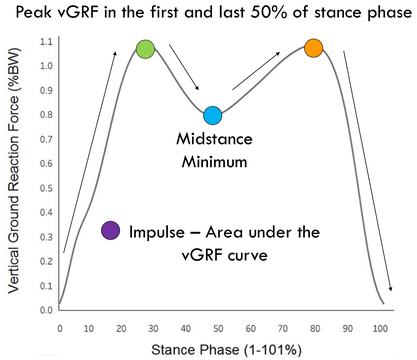

Figure 1: Graph of vertical Ground Reaction Force going through Stance Phase

Table 2: Demographic Information by Group

	Full Sample (n=61)	Cluster 1 (n=33)	Cluster 2 (n=28)	p value
Sex, n participants (%)				0.587
Male	26 (42.6%)	13 (39.4%)	13 (46.4%)	
Female	35 (57.4%)	20 (60.6%)	15 (53.6%)	
6-month Body Mass Index (kg/m2)	24.9 ± 4.5	23.9 ± 3.4	25.6 ± 4.6	0.258
6 Month Gait Speed (m/s)	1.23 ± 0.1	1.30 ± 0.08	1.19 ± 0.09	0.003*
Age (years)	21.6 ± 4.5	20.4 ± 4.4	22.9 ± 4.2	0.025*

*Indicates statistical difference (p<0.05)

	Cluster 1	Cluster 2	p value
KOOS – QOL Score	54.30 ± 15.93	52.50 ± 13.73	0.74
KOOS – ADL Score	97.15 ± 4.99	95.26 ± 5.93	0.30
KOOS – Sport & Rec Score	67.19 ± 16.92	67.20 ± 21.12	0.99
KOOS – Pain Score	86.46 ± 7.58	82.56 ± 12.15	0.25
KOOS – Symptoms Score	81.70 ± 10.66	78.87 ± 10.31	0.41

Table 3: Cluster KOOS subscale means, standard deviation, and p values

DISCUSSION

- The current study suggests that gait biomechanical profiles best identify subgroups of ACLR patients within 6 months post-ACLR.
- Although the higher loading group demonstrated better gait biomechanics than the low loading group, both groups exhibit lower peak vGRF in comparison to uninjured controls.[6]
- However, there were no between-group differences in the KOOS subscales at six-months post ACLR.

Limitations:

- This is a preliminary analysis of an ongoing longitudinal cohort study
- Some observations were omitted due to missing data points

Future Directions:

- ACLR patients exhibit different biomechanical profiles following ACLR and each subgroup may benefit from personalized interventions and rehabilitation plans to meet specific needs.

REFERENCES

1. Calvert, A. et al, *JAMA* (2013).
2. Wasserstein, D et al. Osteo Cartil (2015).
3. Spindler, K. et al, *American J of Sports Medicine* (2018).
3. Duun, W .et al. , *American J of Sports Medicine* (2010).
4. Lisse, C. et al, *Medicine & Science in Sports & Exercise* (2022).
5. Pfieffer, S. et al, *Arthritis Care and Research*. (2017).
6. Davis-Wilson, H. et al, *Medicine & Science in Sports & Exercise (2020)*.

Contact Information:
Erin Carico
erincarico@unc.edu