Longitudinal Analysis of ACL Rehabilitation:

Analyzing Adjusted Torque to Identify Early-Stage Recovery Plateaus

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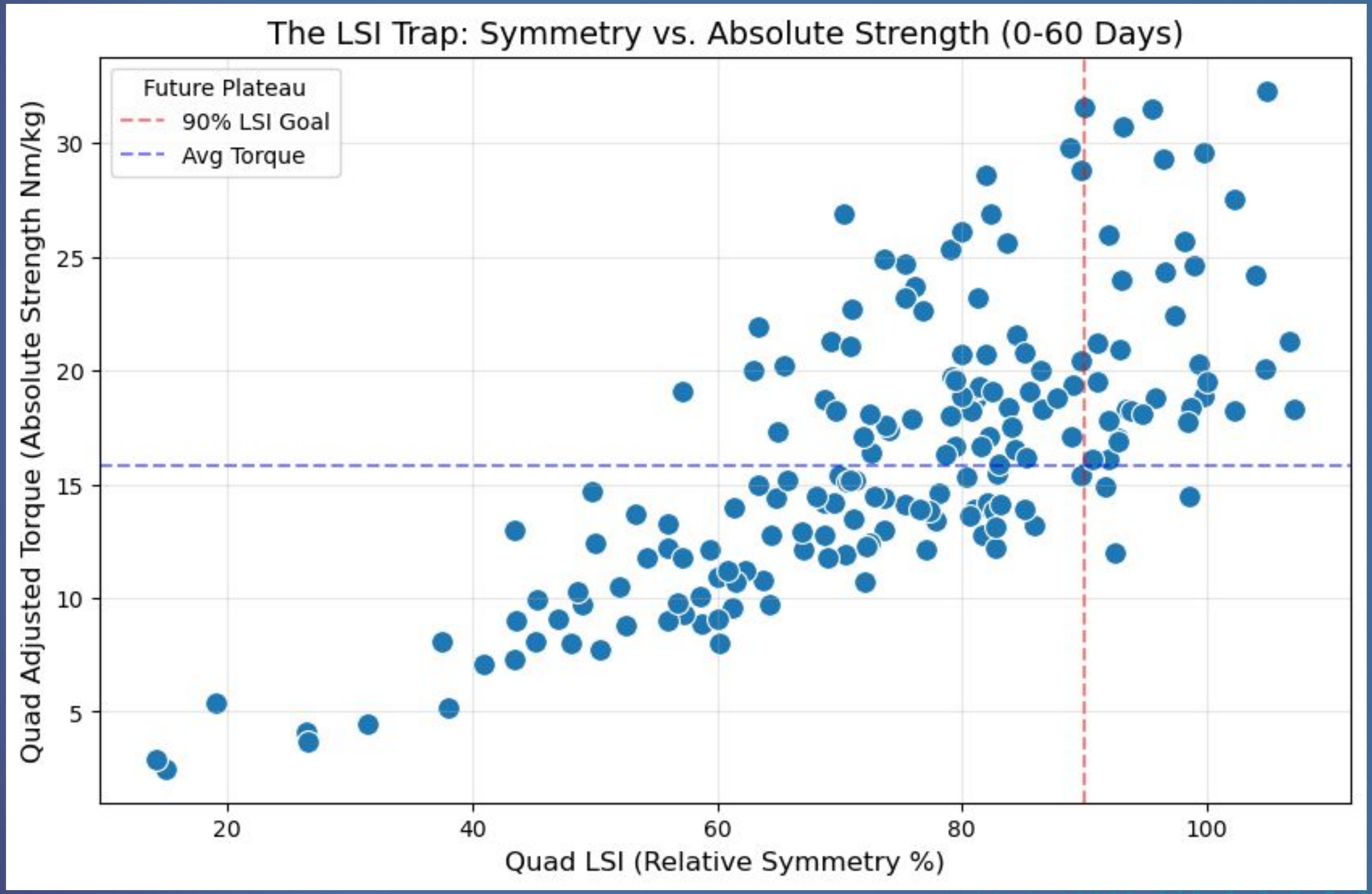
The Problem: The "LSI Trap"

Current Standard: Physical Therapy relies on the Limb Symmetry Index (LSI) and time-based protocols (Compagnin et al., 2025)].

Flaw: LSI can be a "false positive." If the uninjured limb loses strength, an athlete can hit 90% symmetry while remaining functionally weak (Sheenam et al., 2025).

Consequence: Secondary injury rates reach 23% in young athletes (Wiggins et al., 2016).

Objective: Move beyond symmetry to complete functional capacity.



Related Work & Benchmarks

Muscle Atrophy

Quad thickness drops ~20% in the first 30 days post-op (Sheenam et al., 2025)

Clinical Signaling

Research identifies Adjusted Torque (AUC: 0.76) as a more reliable functional indicator than LSI (AUC: 0.62) (Pietrosimone et al., 2016).

The Research Gap

Most existing studies (e.g., Pietrosimone et al., 2016) analyze late-stage recovery in controlled lab settings.

Current Study Focus

Identifying clinical signals within the "messy" early-stage (0–60 days) real-world clinical window.

Methodology

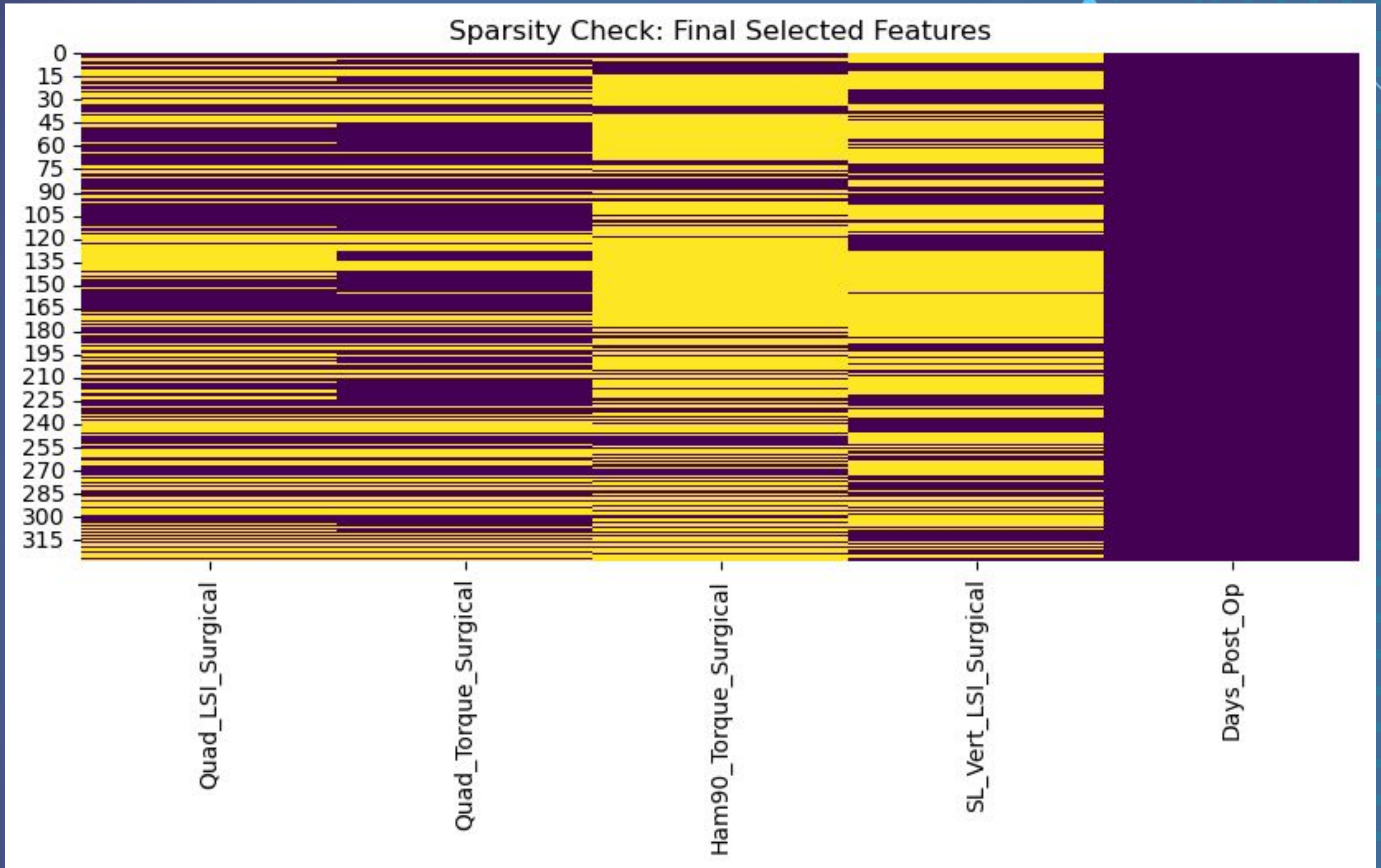
Data Science Lifecycle: Consolidated seperate athlete workbooks into a de-identified/normalized master dataset.

Data Cleaning: Resolved a date error; filtered for ≥ 14 days post-op to remove surgical "noise" (Alqahtani et al., 2025).

Modeling Strategy: Multivariate Logistic Regression chosen for clinical interpretability (Zhu, Kelly, et al., 2025).

Features: Mean Quad LSI vs. Mean Adjusted Torque (0–60 days).

Target: "Plateau" = <90% Peak LSI or <5% improvement in final visits.

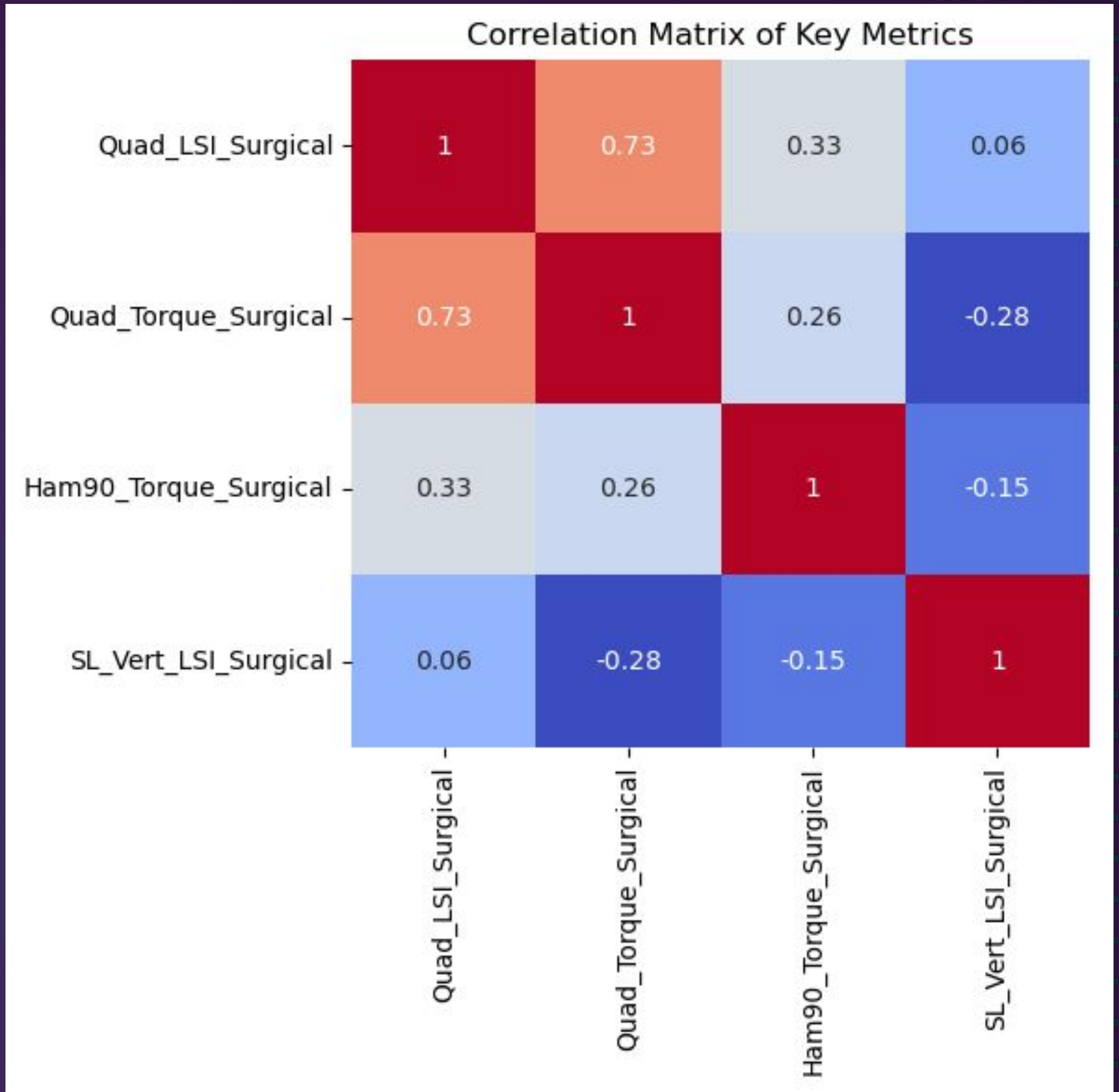


Visualizing the Findings

Feature Relation: Correlation of r=0.73 between LSI and Torque confirms they provide distinct info.

Data Quality: Sparsity analysis identified structural missingness (testing is only done on specific days).

Significance: Small sample size (n=18) requires focus on effect size over p-values (Vabalas et al., 2019).

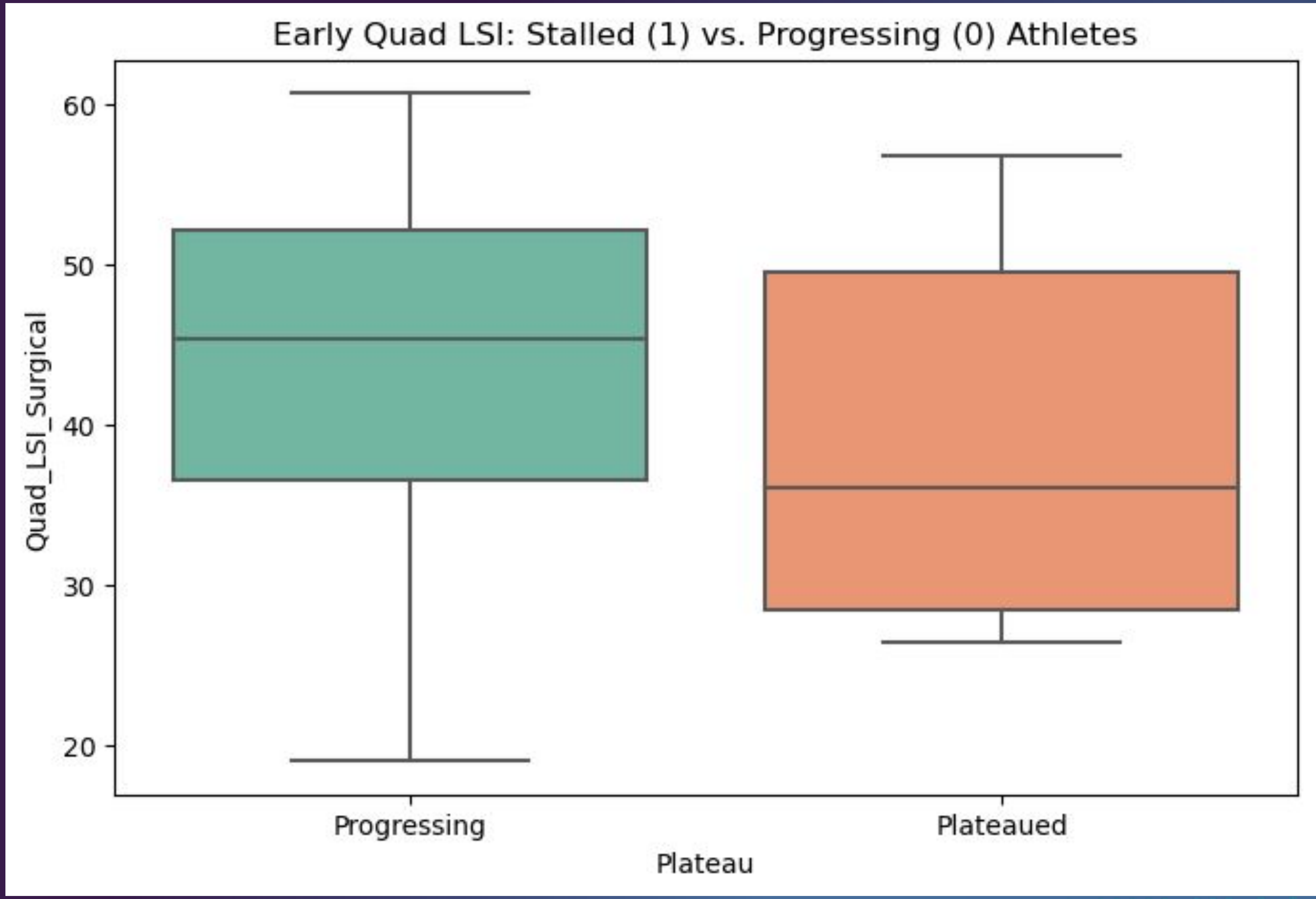


Results

Predictive Signal: Multivariate model (AUC: 0.71) significantly outperformed LSI-only (AUC: 0.59).

The Discovery: A critical threshold of 6.79 Nm/kg was observed at Day 60.

Model Coefficients: Torque (−0.212) has a strong negative correlation with plateau risk; LSI (0.018) has negligible impact.

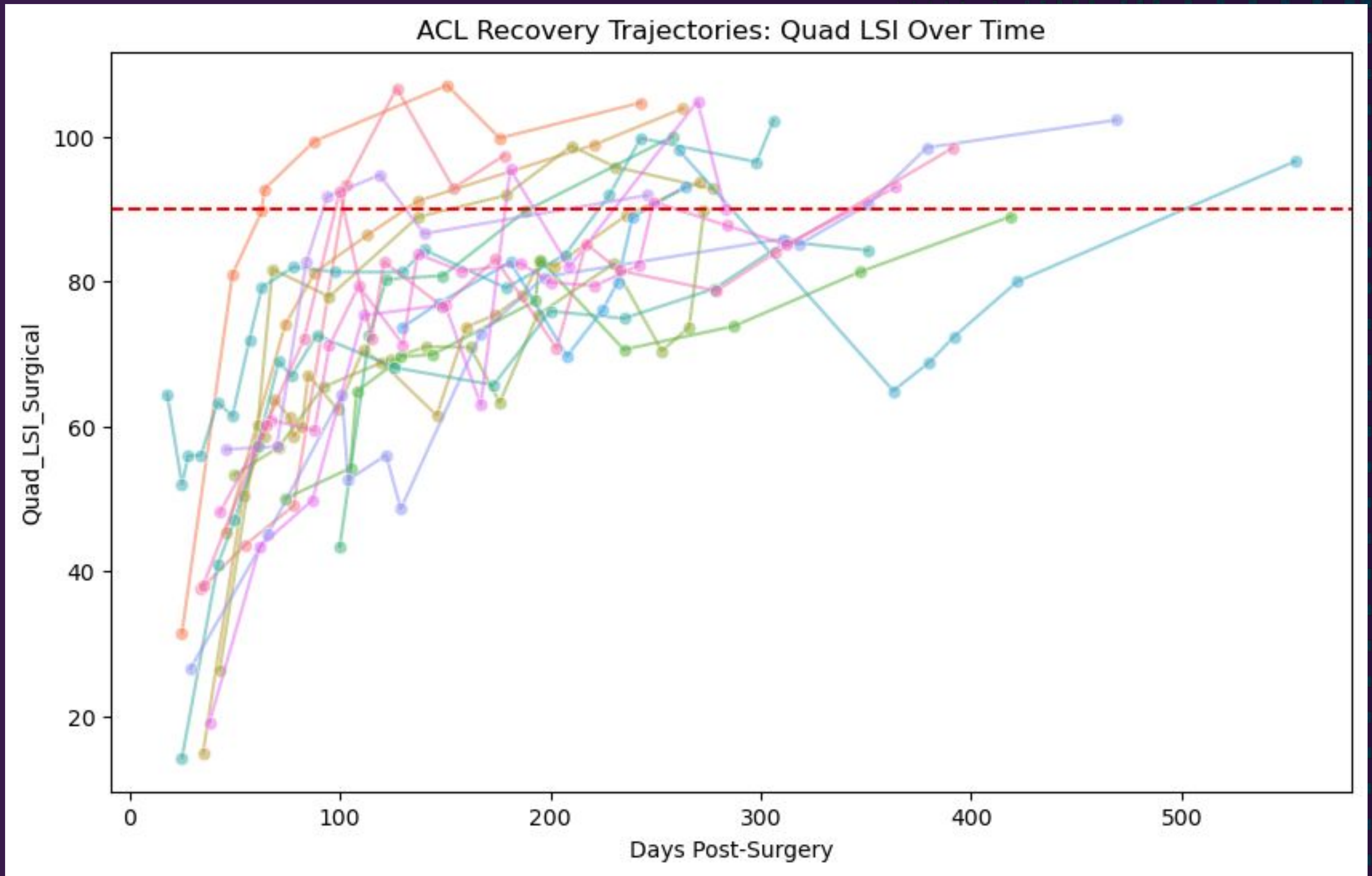


Recovery Trajectories

Visual Evidence: Individual trajectories show non-linear recovery (some stall, some steady).

The Intervention Zone: Focusing on the first 60 days allows for earlier clinical pivots.

Discussion: 6.79 Nm/kg serves as a "Red Flag" to help PTs identify athletes who are "symmetrically weak."



Conclusion & Future Work

Key Takeaway: Adjusted Torque is a superior early-stage signal for identifying plateaus.

Clinical Impact: Provides a quantitative framework for PTs to move beyond manual, visual follow-ups.

Next Steps

- Expand cohort size for model stability.
- Integrate findings into real-time clinician dashboards.
- Validate 6.79 Nm/kg threshold across multiple clinical settings.

Resources

Alqahtani, T. A., Kardm, S. M., Alnakhli, H. H. et al. (2025). Impact of early vs. delayed physical therapy on functional recovery, proprioception, and return to sport after anterior cruciate ligament (ACL) reconstruction: a cross-sectional study. Journal of Orthopaedic Surgery and Research, 20(644).

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Sheenam, N., Gaur, R., Gonnade, N. M. et al. (2025). Knee functional outcomes and quadriceps hypotrophy after ACL reconstruction: a prospective observational study. BMC Sports Science, Medicine and Rehabilitation, 17(120).

Vabalas, A., Gowen, E., Poliakoff, E., & Casson, A. J. (2019). Machine learning algorithm validation with a limited sample size. PLoS One, 14(11), e0224365.

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Zhu, X., Kelly, D. K., Kim, G., Hart, J. M., & Gong, J. (2025). Clinically interpretable modeling of ACL reconstruction outcomes using confidence-aware gait analysis. Biomechanics, 5(4), 94.