Loading Levels in Patellar Tendon, Quadriceps Tendon, and Patellofemoral Joint Across 35 Rehabilitation Exercises

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Introduction

Patellar and quadriceps tendinopathy and patellofemoral pain are prevalent knee joint pathologies, particularly affecting physically active individuals. Yet state-of-the-art knee rehabilitation protocols often rely on clinician perspectives, potentially leading to suboptimal recovery outcomes. Progressive loading promotes tissue healing, but the loading levels in knee tendons and the patellofemoral joint have not been quantified for most common rehabilitation exercises. As such, clinicians need more quantitative evidence to refine knee rehabilitation plans that progress therapeutic loading and suit patient-specific recovery goals. We recently developed a "Loading Index" based on loading peak, impulse, and rate to define overall loading "tiers" in the Achilles tendon during various exercises.[1] In this study, our goal was to establish a Loading Index to quantify, compare, rank, and categorize loading levels in the patellar tendon, quadriceps tendon, and patellofemoral joint across 35 common clinical knee rehabilitation exercises and routine activities.

Methods

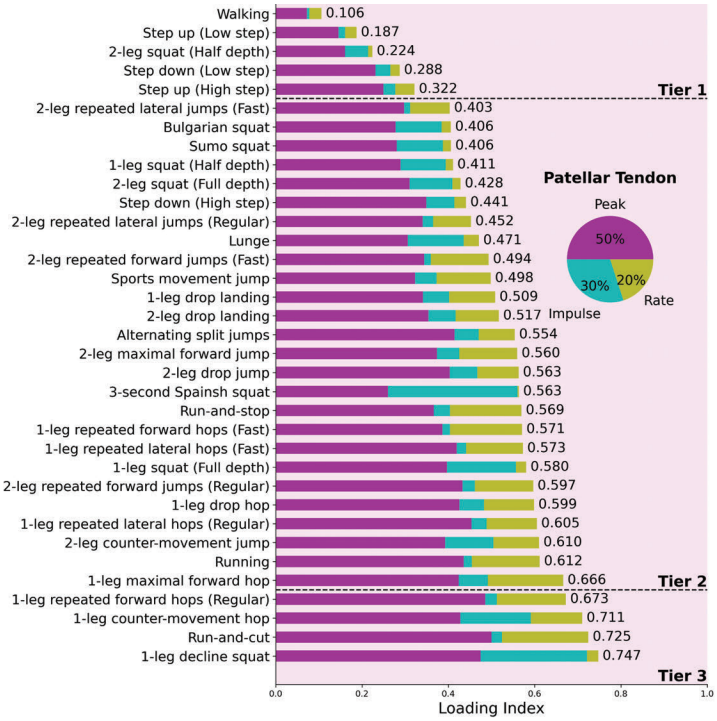
We recruited 20 healthy adult subjects (10F, 25.9 ± 5.7 years, body mass index = 24.1 ± 2.6 kg/m2) who had no self-reported knee pain or injury, and obtained their informed consent for this IRB-approved study. We recorded motion data of each subject performing 35 knee rehabilitation or routine exercises (Figures 1-3), and calculated knee flexion angles and moments using an inverse dynamics biomechanical model. Next, we estimated load in the patellar tendon, quadriceps tendon, and patellofemoral joint based on the knee flexion angles and moments, using effective tendon moment arms and force relationships among the 3 knee structures defined in literature.[2-4] We normalized each knee structure load by subject weight, zeroed negative force components to account for physiologically one-way loading, then calculated their peak, impulse, and rate metric during each exercise. We calculated the Loading Index of each exercise as a weighted sum of the group-average of each loading metric.[1] For knee tendons, we set 50% Loading Index weight on loading peak, 30% on impulse, and 20% on rate, similar to our Achilles tendon study.[1] For patellofemoral joint, we set 50% weight on loading peak and 50% on impulse based on our perspective on their relative clinical importance. To compare the overall loading levels in each knee structure across all 35 exercises, we ranked their Loading Indices in an ascending order, then categorized them into 3 equally-divided tiers, from Tier 1 (low, i.e. < 0.333) to Tier 3 (high, i.e. > 0.667).

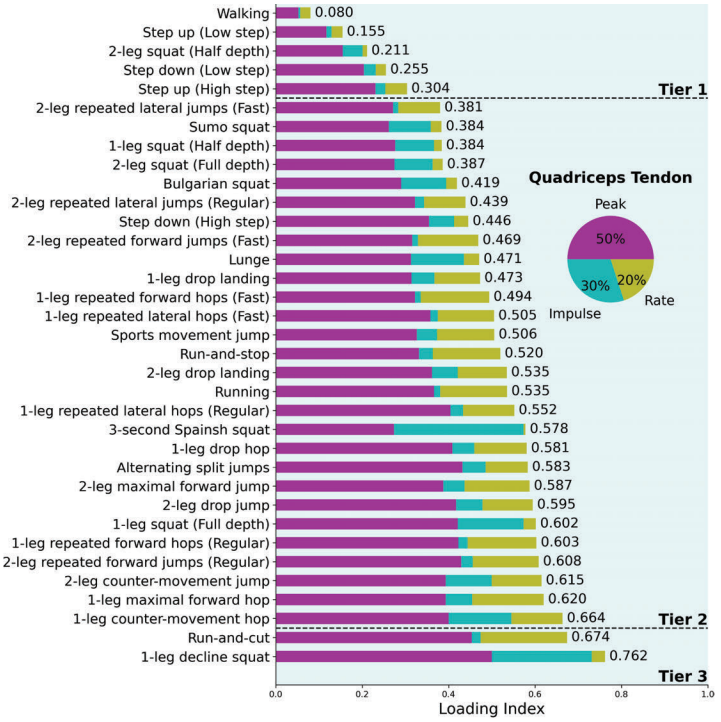
Results

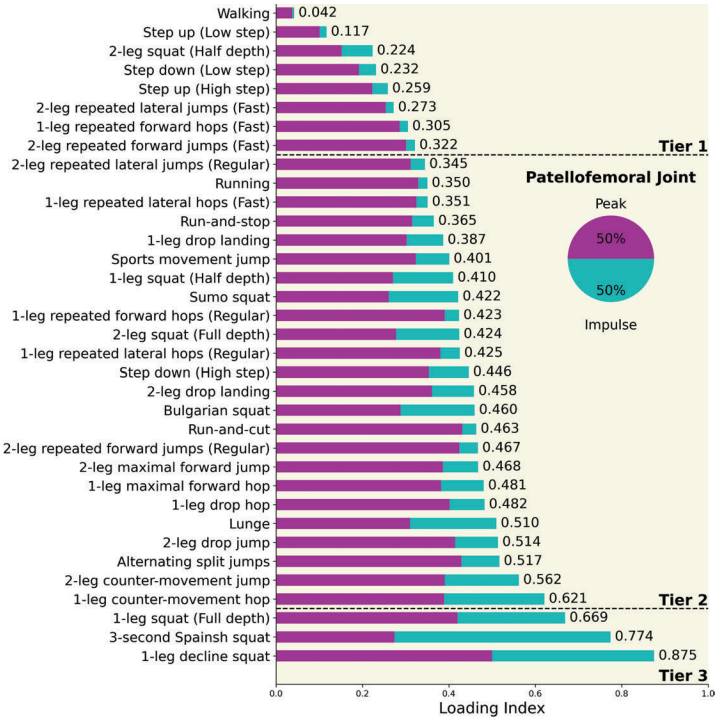
Overall loading levels in each knee structure varied substantially across exercises (Figures 1-3). Most rehabilitation exercises fell into Tier 2 ($0.333 <$ Loading Index < 0.667), suggesting they provide moderate knee loading. Few exercises provide low-level loading (Tier 1) that resembles routine walking, while single-leg decline squat was the only exercise that generate highest-level loading in all 3 knee structures (Tier 3). For many exercises with moderate or high loading levels, loading peak, impulse, and rate varied between fast-speed exercises (e.g. run-and-cut) and long-duration exercises (e.g. Spanish squat). Loading ranks were generally similar among the 3 knee structures, yet for quadriceps tendon and patellofemoral joint forces, there is a notable bias towards higher Loading Index for high knee flexion exercises. Notably, exercises with long duration and high knee flexion (e.g. squats) saw a relative shift up the ranks while many fast-speed but short-duration exercises (e.g. running and jumping) moved down the ranks substantially.

Discussion

Our results show that most rehabilitation exercises feature a moderate level of knee structure loading, while few exercises provide low level of loads that resemble walking, or







Figures 1-3. Loading Indices ranked for patellar tendon, quadriceps tendon, and patellofemoral joint forces across 35 rehabilitation exercises, categorized low (Tier 1), moderate (Tier 2), and high (Tier 3). Loading Index weights for patellar and quadriceps tendons are 50% on loading peak, 30% on impulse, and 20% on rate. Weights for patellofemoral joint are 50% on loading peak and 50% on impulse.

loading with both high magnitude and long duration. Exercises with a moderate level of knee structure loading provide the most diverse opportunities for patient-specific rehabilitation planning, as clinicians can simplify protocols and choose mechanically similar exercises that best suit patient needs and abilities during rehabilitation. Conversely, the scarcity of low-loading exercises suggest that clinicians should use caution when prescribing early-stage exercises to avoid tissue over-loading that poses risks of healing complication. While many fast exercises feature high level patellar tendon loading, exercises with high knee flexion often generate higher quadriceps tendon and patellofemoral joint loading. We thus recommend clinicians differentiate loading profiles among the 3 knee structures and adjust rehabilitation strategies to progress therapeutic loading on the healing knee structure.

Significance

To our knowledge, this study is the first to quantify loading in three knee structures across a large collection

of exercises in the same cohort. Our findings provide straightforward tools for clinicians to design rehabilitation protocols that prescribe progressive therapeutic loading while suiting patient-specific recovery needs, and set a benchmark for future research on complex and chronic knee pathologies.

Acknowledgments

NIH R01AR078898, R01AR072034, R37HD037985. We thank Audrey Lehneis and Liliann Zou for their assistance with data processing. This work was also presented at the 69th Annual Meeting of the Orthopaedic Research Society (ORS) on February 10 – 14, 2023 in Dallas, Texas.

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