Biomechanical Assessment of Three Patellar Advancement Procedures for the Treatment of Patella Alta in Children with Cerebral Palsy

Adam Seidl, MD¹, Todd Baldini, M.Sc.¹, Jason Rhodes, MD², James Carollo, PhD, PE².
¹University of Colorado - Denver, Aurora, CO, USA, ²Children’s Hospital Colorado, Aurora, CO, USA.


Introduction: In crouch gait deformity, individuals with cerebral palsy walk with higher than normal hip and knee flexion (1). The extreme knee flexion generates large knee extension moments that cause 2 to 3 times higher than normal patellar tendon loads. Crouch gait also prolongs the duration of these loads (1). These combined actions result in increased stress on the viscoelastic patellar tendon, creep, and often patella alta (2). This vicious cycle may eventually lead to non-functional gait and loss of ambulation (2). Therefore, it is essential to detect patella alta early and restore the normal alignment of the patella before walking is permanently disrupted.

Patellar tendon advancement for the treatment of patella alta and crouch gait deformity is a relatively new surgical procedure. Several variations of this operation are performed. Unfortunately there are accounts of acute failure at the patellar tendon repair site and early recurrence of patella alta (3). Biomechanical testing using fresh frozen cadaveric specimens has been used to evaluate patellar tendon strength in other studies but no current research has compared the three most common procedures for treating patella alta. The purpose of this study was to determine which of three surgical techniques is biomechanically optimal for patellar tendon advancement in the treatment of patella alta using a cadaveric model.

Methods: The 24 human cadaveric knees, 8 per group, used in this biomechanical study were prepared using one of 3 different surgical techniques:
(1) Resection of proximal patella tendon with patellar advancement and fiberwire repair through longitudinal drill holes through the patella.
(2) Imbrication of the mid-portion of patella tendon with repair using running locking suture
(3) Distal advancement of the patella tendon with tibial tubercle osteotomy and fibertape augmentation
The knees were mounted to the base of a servo-hydraulic test machine at a fixed flexion angle of 45°. The quadriceps tendon was freed and connected to the actuator with a cryo-clamp. The quadriceps was loaded from 25N to 250N in 0.1 seconds, held at 250N for 0.4 seconds, and unloaded to 25N in 0.1 seconds, and held at 25N for 0.4 seconds for 1,000 cycles. This loading configuration simulates a 60% stance/40% swing gait cycle of 1 second duration (4). The knees were then tested to failure at 3.33mm/sec.

To measure proximal patella migration relative to the tibia, optical markers were placed on the patella and the tibia. Motion was captured at 30 frames per second with a digital camera and tracked with motion analysis software. Displacement of greater than 5 mm at the repair site was considered repair failure. The peak displacement of the patella was measured at 1, 10, 25, 50, 100, 250, 500, 750, and 1000 cycles for each of the constructs. The peak load at which failure occurs and the overall stiffness of each construct was recorded.
For the cyclical loading test, non-linear response data was log converted allowing data to be fit to a mixed effects linear model with random coefficients. The slopes of these 3 linearized curves were then pairwise compared to look for significant differences using each model’s t-statistic at an alpha level of 0.05. Post-hoc power analysis was then performed to confirm the sample size was sufficient. One-way analysis of variance (ANOVA) was used to compare mean values for the constructs load to failure and stiffness. Post-hoc Tukey HSD testing was used to determine individual differences between constructs.

**Results:** A significant difference in repair displacement with cyclical loading was found after comparing the surgical techniques (Fig 1). Tibial tubercle osteotomy exhibited less displacement than distal patella ($P<0.0001$) and imbrication ($P=0.009$). Imbrication exhibited less displacement than distal patella ($P=0.0006$) (Table 1). Post-hoc power analysis showed sufficient sample size for comparisons (Table 1). There was no significant difference (ANOVA $P=0.10$) in load to failure among the three groups, distal patella 768.7N ($\pm352.7$), imbrication 487.4 ($\pm207.6$), and tibial tubercle 958.5N ($\pm434.1$). There was a significant difference in stiffness among the three groups (ANOVA $P=0.008$). The significant difference ($P=0.006$) between groups was the imbrication $83.8N/mm$ ($\pm23.6$) was stiffer than the distal patella $52.6N/mm$ ($\pm14.5$). The stiffness of the tibial tubercle repair $73.2N/mm$ ($\pm14.7$) was not significantly different from the other two groups.

**Discussion:** These data suggest that patellar advancement using the tibial tubercle osteotomy technique provides the strongest biomechanical construct, yielding the least displacement at the repair site with cyclical loading, when compared to alternative surgical techniques. We have shown that under cyclic loading, the tibial tubercle osteotomy repair technique failed later than both the distal patella and imbrication techniques, based on a clinical failure threshold of 5mm. While it is understood that patients with open physes are not candidates for tibial tubercle osteotomy, this study makes a strong argument for the use of this technique over other options in skeletally mature individuals with crouch gait and patella alta. The lack of significance in the ultimate strength testing was associated with high variability in the load to failure data, directly attributable to the use of the same samples from the cyclical loading test that likely exhibited plastic deformation during the testing. We believe the necessity to use the same samples based on availability of specimens biased the load to failure data, so our conclusions are based on the cyclical loading data alone.

Previous studies have supported the use of tibial tubercle osteotomy patellar advancement with or without concomitant distal femoral extension osteotomy for the treatment of patella alta (5). Specifically, Stout et al. reported on a series of patients with persistent crouch gait supporting the use of patellar tendon advancement (6). It was concluded that patellar tendon advancement has the potential to restore knee and hip joint kinematics to values within typical limits as well as promote gains in community function (6). Das et al. reported a series of patients treated with this operation and found that it is effective in improving knee extensor strength, reducing knee pain and improving function (7). Of note, the majority of patients in both of these studies underwent concomitant distal femoral extension osteotomy.

**Significance:** Patella alta is a serious problem in many children with cerebral palsy and crouch gait which must be addressed to restore the biomechanics of the extensor mechanism of the knee. It is the authors’ belief that this study adds a biomechanical component to previous studies offering clinical and kinematic support for the use of patellar advancement in patients with crouch gait and patella alta.
### Table 1 Displacement Slope Comparisons for Linear Mixed Effects Model in Cyclic Loading

| Slope Difference Comparison          | Estimate | Standard Error | DF  | t Value | Pr > |t| | p<0.05? | Post Hoc Power at 0.05 |
|-------------------------------------|----------|----------------|-----|---------|------|---| |        |                          |
| Tib Tubercle vs. Distal Patella     | -0.1738  | 0.0283         | 164 | -6.13   | <.0001 | Y | |        | 100.0%                   |
| Tib Tubercle vs. Imbrication        | -0.0751  | 0.0283         | 164 | -2.65   | 0.0088 | Y | |        | 75.00%                   |
| Distal Patella vs. Imbrication      | 0.0987   | 0.0283         | 164 | 3.48    | 0.0006 | Y | |        | 93.37%                   |

#### Figure 1
Average Displacement During Cyclic Loading (standard error bars).

**ORS 2015 Annual Meeting**

**Poster No: 0772**