Medial patellofemoral ligament (MPFL) reconstruction improves radiographic measures of patella alta in children

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Background: Patellofemoral instability has previously been associated with patella alta. The purpose of this study was to evaluate adolescents undergoing MPFL reconstruction for standardized indices of patellar height on pre- and post-operative radiographs to determine if these radiographic parameters change after MPFL reconstruction.

Methods: Twenty-seven children (mean age 14.9 years old) who underwent MPFL reconstruction without a distal realignment procedure were evaluated pre- and post-operatively for Insall–Salvati Ratio, Modified Insall–Salvati Ratio, and Caton–Deschamps Index by three blinded raters. Intrarater reliability and interrater reliability were calculated for each index, and means of each were compared pre- and post-operatively to determine if MPFL reconstruction was associated with improved patellar height.

Results: All three indices of patellar height indicated that there was patella alta present in this cohort preoperatively. Inter-rater reliability was excellent for both the Insall–Salvati Ratio (ICC = 0.89) and Caton–Deschamps Index (ICC = 0.78), and adequate for the Modified Insall–Salvati Ratio (ICC = 0.57); intrarater reliability was excellent for all three (ICCs: 0.91, 0.82, 0.80 respectively).

Conclusions: MPFL reconstruction in children using hamstring autograft was associated with consistently improved patellar height indices to within normal childhood ranges. This associated improvement of patellar height as measured on a lateral radiograph may subsequently improve patellofemoral mechanics by drawing the patella deeper and more medially into the trochlear groove.

Level of Evidence: Level 4.

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1. Introduction

Patellofemoral dislocation is a common knee injury in children and adolescents. It accounts for up to 2% to 3% of all knee injuries, and occurs at a rate of 29 to 43 per 100,000 in the population aged 10 to 17 years old [1]. Further, it is the second leading cause of hemarthrosis in adolescents aged 13 to 16 years old [2]. Despite its common diagnosis, patellofemoral dislocation presents a diverse variety of pathology: Green’s classification of patellofemoral instability in children and adolescents notes syndromic, obligatory, fixed lateral, and traumatic types, with traumatic dislocations representing the greatest majority of reported pediatric cases [3]. While syndromic dislocators are predisposed to frequent or fixed patellar dislocation due to connective tissue laxity, incompetent collagen supporting structures, trochlear dysplasia, and lower extremity deformity [3], traumatic dislocators by definition have an inciting event which disrupts the normal supporting structures of the patellofemoral joint, causing lateral patellar dislocation. With subsequent dislocation events, the medial supporting structures weaken and lower energy trauma is required to cause instability.

In addition to the attenuation of the medial supporting structures, patella alta has been historically postulated to increase the risk of patellofemoral dislocation. Patella alta draws the patella out of the osseous confines of the trochlear groove, requiring increased knee flexion angles to engage the trochlea and decreasing its inherent stability thereby placing more emphasis on the medial patellofemoral ligament (MPFL) to act as a check rein and hold the patella in a reduced position. Numerous studies [4–16] and meta-analysis [17] have reported that patella alta is a predisposing factor for patellar instability and recurrent dislocation, and recent literature favors MPFL reconstruction to restore these patellar kinematics [3,18–26].

While it has been widely published that patella alta is associated with patellar instability, it remains unclear if MPFL reconstruction increases stability through an indirect correction of patella alta. The
The purpose of this study is to evaluate adolescents undergoing MPFL reconstruction for standardized indices of patella alta on pre- and post-operative radiographs to determine if these parameters are associated with correction after MPFL reconstruction. We hypothesized that existing preoperative patella alta would improve postoperatively, which would indicate that MPFL reconstruction may stabilize the patella by two complimentary mechanisms: reconstruction of the major dynamic medial supporting structure as well as the indirect improvement of patellar height. Optimizing patellar height could potentially restore static osseous congruity by drawing the patella deeper into the trochlear groove over a greater range of flexion angles.

2. Patients

This study was approved by the hospital’s Institutional Review Board. Hospital records of a single surgeon at an urban tertiary care academic orthopedic hospital were reviewed for eligible cases from the inception of the current surgical technique (May 2008) through three months prior to the beginning of data analysis (August 2012). This allowed for the collection of preoperative and three month postoperative radiographs of a uniform surgical technique for comparison. Cases were included if patients were under age 18 and underwent an index primary MPFL reconstruction without concomitant procedures of the tibial tubercle (e.g. Fulkerson osteotomy, Maquet osteotomy, Elmslie–Trillat procedure, distal soft tissue realignment) for traumatic recurrent patellofemoral instability. This yielded 27 children for inclusion in the study. Of the included patients, there were five boys and 22 girls with a mean age of 14.9 years old. Distal femoral physeal closure was complete in 10 of the 27 patients (37%).

3. Methods

3.1. Surgical indications and technique

For children who sustain a primary traumatic patellofemoral dislocation without an intraarticular loose body noted on MRI, initial treatment is nonsurgical, and focuses on quadriceps strengthening and improving core stability. Children are indicated for MPFL reconstruction if they sustain recurrent patellofemoral dislocations despite an organized course of conservative treatment (e.g. physical therapy) after their first dislocation.

The surgical technique employed in this study has been previously described [27], and is a modification of the technique described by Schottle et al. [28]. In short, a doubled hamstring autograft was used to reconstruct the MPFL with tenodesis screws placed under fluoroscopic guidance between the superior half of the medial aspect of the patella and a femoral attachment site, which was determined by the patients’ skeletal maturity (Fig. 1). In patients who are skeletally mature, the patellar limbs were fixed first, with length set by adjusting the amount of tendon graft placed into the femoral socket which is fixed second. In children with open physes, the femoral limb is attached first, with tenodesis set via the femoral limb which was fixed second. In the skeletally mature, the femoral socket is placed in line with the posterior femoral cortex. In children who are skeletally mature, the patellar limbs were fixed first, with tension set via the femoral limb which was fixed second. In the skeletally mature, the femoral socket is placed in line with the posterior femoral cortex at the level of the physeal scar.

3.2. Radiographic evaluation

All patients had preoperative and three month postoperative knee radiographs which were evaluated by three raters (the treating orthopedic surgeon and two orthopedic residents) for each of three indices of patellar height: Insall–Salvati Ratio [29], Modified Insall–Salvati Ratio [30], and Caton–Deschamps Index (Fig. 2) [31]. All images were de-identified and randomized in order to blind the raters. Each rater evaluated each radiograph, which was placed in random order and blinded by an independent third party, and each measure of patellar height was calculated and recorded. Intrarater reliability and interrater reliability were calculated for each index, and means of each were compared pre- and post-operatively to determine if patellar height changed after MPFL reconstruction in the absence of a distal...
realignment procedure. Average pre- and post-operative values were compared to normally accepted childhood ranges.

3.3. Statistical methods

Statistical analyses were performed by a member of the research team with advanced training in biostatistics using SAS Software version 9.3 (SAS Institute, Inc., Cary, North Carolina, USA). Descriptive statistics were used to evaluate the distribution of continuous data. After establishing data normality, paired Student’s t-tests were used to evaluate for postoperative changes in each of the continuous measures of patellar height. McNemar’s test for paired categorical data was used to compare categories of normal vs. abnormal ranges of patellar height preoperatively and postoperatively. Intraclass correlation coefficient (ICC 2,1) was used to quantify interrater reliability and intrarater reliability for each measure of patellar height. This investigation was a retrospective study of all available patients who met inclusion criteria, and therefore an ad-hoc power calculation was not possible [32]. All analyses that generated P-values were two-tailed and used P = 0.05 as the threshold for statistical significance.

4. Results

4.1. Interrater reliability and intrarater reliability

Interrater reliability was excellent for both the Insall–Salvati Ratio (ICC = 0.89) and Caton–Deschamps Index (ICC = 0.78), and adequate for the Modified Insall–Salvati Ratio (ICC = 0.57). Intrarater reliability was excellent for all three indices: Insall–Salvati Ratio (ICC = 0.91), Caton–Deschamps Index (ICC = 0.82), and Modified Insall–Salvati Ratio (ICC = 0.80).

4.2. Patellar height

Mean preoperative and postoperative measures of patellar height along with normal values are displayed in (Table 1). All three indices of patellar height indicated that there was patella alta present in this cohort. Furthermore, all three measures significantly improved postoperatively (paired t-test, P < 0.001 for all) by 11.3% to 15.8% on average. All three radiographic measures of patellar height fell within normal childhood ranges postoperatively.

When applying criteria of normal ranges of each radiographic index of patellar height to each patient, the number of children who had abnormal values improved for each measure. For Insall–Salvati Ratio, 19 patients (70%) were abnormal preoperatively compared to 12 (44%) postoperatively (McNemar’s test; P = 0.02). For Modified Insall–Salvati Ratio, 20 patients (74%) were abnormal preoperatively compared to 12 (44%) postoperatively (McNemar’s test; P = 0.01). For Insall–Salvati Ratio, 18 patients (67%) were abnormal preoperatively compared to 8 (30%) postoperatively (McNemar’s test; P = 0.004).

Subgroup analyses of skeletal maturity and gender noted no differences in improvement in patellar height indices (P > 0.05 for all). There were no complications or episodes of recurrent patellofemoral instability in this cohort.

5. Discussion

The current study confirmed the hypothesis that MPFL reconstruction was associated with improved patellar height in the setting of patellar instability, indicating that MPFL reconstruction may work by both restoring the main dynamic medial patella stabilizer as well as restoring static stabilization by directing the patella medially and distally into the trochlear groove. The etiology of this finding is likely multifactorial: by performing ligament reconstruction, the medial check rein inhibits the patella from escaping the trochlea superolaterally, a slightly distally-oriented graft may also decrease patellar height, and medializing the resting state of the patella geometrically lowers the patella even in the absence of distal realignment procedures. These results are useful to surgeons performing MPFL reconstruction, as the improvement of patella

### Table 1

Improvements in three indices of patellar height after MPFL reconstruction in children.

<table>
<thead>
<tr>
<th>Patella height measurement</th>
<th>Normal range</th>
<th>Mean ± SD preoperative value</th>
<th>Mean ± SD postoperative value</th>
<th>Mean absolute improvement</th>
<th>Mean % improvement</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insall–Salvati Ratio</td>
<td>&lt;1.25a</td>
<td>1.41 ± 0.27</td>
<td>1.25 ± 0.22</td>
<td>0.16</td>
<td>11.3%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Modified Insall–Salvati Ratio</td>
<td>&lt;2.00a</td>
<td>2.24 ± 0.30</td>
<td>1.97 ± 0.19</td>
<td>0.27</td>
<td>12.1%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Caton–Deschamps Index</td>
<td>&lt;1.27b</td>
<td>1.39 ± 0.25</td>
<td>1.17 ± 0.19</td>
<td>0.22</td>
<td>15.8%</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a Reported values in literature [29,30].
b Mean normal value reported in literature plus 1 standard deviation [31].
alta in the absence of a tibial tubercle distalization may allow for the avoidance of an unnecessary additional surgical procedure. What remains uncertain, however, is whether the preoperative patella alta predicted the initial injury, or if it was a result of traumatic patellofemoral instability and an MPFL tear itself.

The topic of patella alta as an independent risk factor or result of patellofemoral instability remains unclear. While many authors have previously reported that patients with patellofemoral instability have greater rates of patella alta [4–16], we speculate that this may be due in part to the MPFL rupture itself. It is known that the MPFL is an obliquely-oriented structure with an origin on the patella more proximal than the distal insertion on the femur [33]. Therefore, disruption of this important structure may itself contribute to the patella alta that is measured on injury radiographs, but has previously been reported as a “risk factor” despite the lack of longitudinal radiographic data. While we have shown that restoring the distally-orientated MPFL was associated with improved patellar height indices to within normally accepted ranges for these measurements, the chronicity of this phenomenon remains uncertain. These conclusions are corroborated by similar findings by Lykissas et al. in the pediatric orthopedic literature [34]. In order to determine chronicity, otherwise healthy children would need to be exposed to ionizing X-ray radiation for baseline patellar height measurements in order to truly determine if patella alta is a risk factor or a consequence of patellofemoral instability; a study such as this is unlikely to be performed due to ethical concerns.

Previous studies have shown that there is an association between patella alta and patellofemoral instability, however attempting to causatively link the two is problematic for several reasons: 1) comparison groups with different pathologies have a high risk of noncomparability as described above, 2) using the contralateral knee for comparison is problematic as there may be significant natural side-to-side differences in patellar height [35], and 3) longitudinal study of radiographs of adolescent knees with patellofemoral instability may be problematic as patellar height changes with development. Lykissas et al. [34] did, however, show an improvement in patellar height to within normal ranges postoperatively using slightly different reconstruction techniques (gracilis autograft with one patellar limb, tensioning in 45° of flexion) than the one employed in this study which confirms our results.

While the actual patellar tendon length does not change after MPFL reconstruction, the measurement of patella alta on a two-dimensional lateral radiograph does improve. The MPFL acts as a check and a tensioner and a medialized resting position of the patella; this new medialized resting state in and of itself may also lower the patella on the lateral radiograph despite a constant patellar tendon length [36]. Therefore, disruption of this important structure may itself contribute to the patella alta that is measured on injury radiographs, but has previously been reported as a “risk factor” despite the lack of longitudinal radiographic data. While we have shown that restoring the distally-orientated MPFL was associated with improved patellar height indices to within normally accepted ranges for these measurements, the chronicity of this phenomenon remains uncertain. These conclusions are corroborated by similar findings by Lykissas et al. in the pediatric orthopedic literature [34]. In order to determine chronicity, otherwise healthy children would need to be exposed to ionizing X-ray radiation for baseline patellar height measurements in order to truly determine if patella alta is a risk factor or a consequence of patellofemoral instability; a study such as this is unlikely to be performed due to ethical concerns.

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The current study improves upon previous work by calculating the interrater reliability and intrarater reliability for each of three patellar height indices in adolescents. Interrater reliability was excellent for both the Insall–Salvati Ratio and Caton–Deschamps Index, and adequate for the Modified Insall–Salvati Ratio, while intrarater reliability was excellent for all three. This provides useful information toward the evaluation of patient alta in patients with patellofemoral instability. Due to the occasional need for concomitant distal realignment procedures in patients with patellofemoral instability, indices that utilize the relative height of the patella to the tibial plateau are preferred. These methods are advantageous in that they are calculated independent of the length of the patellar tendon and tibial tubercle location. They therefore can change postoperatively in a clinically significant fashion with or without distal realignment, whereas with concomitant distal realignment procedures those that rely on measurement to the tibial tubercle may not change. The current study supports the use of the Insall–Salvati Ratio and Caton–Deschamps Index as reliable measures in the evaluation of children and adolescents with patellofemoral instability.

There are limitations inherent to this study. First, generalizability of these results may be limited as they represent the outcomes of one technique as performed by a single surgeon. Second, while patella alta existed on preoperative lateral radiographs, chronicity may not be inferred from this study design, as discussed above. Without pre-injury radiographs it is impossible to know whether the patella alta was present prior to the initial injury (and represented a risk factor for initial patellofemoral dislocation), or if it was a result of the MPFL disruption itself and noted on injury radiographs. Furthermore, this would not be ascertained even with a prospective study design, as pre-injury radiographs would not have been performed. Likewise, chronicity of the noted improvements in patellar height cannot be guaranteed beyond the study follow-up of three months' time, and whether or not these improvements persist is an area of future research. Finally, the retrospective design of this study, as with any study, increases the risk of bias in both patient selection as well as variable measurement. These potential biases were minimized in this study by...
using all available cases that met inclusion criteria, and having the three independent reviewers measure patella alta on blinded radiographs in random order.

In conclusion, surgical reconstruction of the medial patellofemoral ligament (MPFL) in children using hamstring autograft was consistently associated with lower radiographic measurements of patellar height at three months postoperatively for all three indices to within normal values. This improvement of patellar height could subsequently restore additional static osseous congruity by drawing the patella deeper into the trochlear groove over a greater range of flexion angles, possibly eliminating the need for a concurrent distalization procedure.

Conflict of interest statement

The authors have no relevant conflicts of interest to disclose.

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