

## Adolescent differences in knee stability following computer-assisted anterior cruciate ligament reconstruction

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### Abstract

Anterior cruciate ligament (ACL) surgery is being increasingly performed in the adolescent population. Computer navigation offers a reliable way to quantitatively measure knee stability during ACL reconstruction. A retrospective review of all adolescent patients (<18 years old) who underwent computer-assisted primary single bundle ACL reconstruction by a single surgeon from 2007 to 2012 was performed. The average age was 15.8 years (SD 3.3). Female adolescents were found to have higher internal rotation than male adolescents both pre- (25.6° vs 21.7°, P=0.026) and post-reconstruction (20.1° vs 15.1°, P=0.005). Compared to adults, adolescents demonstrated significantly higher internal rotation both pre- (23.3° vs 21.5°, P=0.047) and post-reconstruction (17.1° vs 14.4°, P=0.003). They also had higher total rotation both pre- (40.9° vs 38.4°, P=0.02) and post-reconstruction when compared to adults (31.56° vs 28.67°, P=0.005). In adolescent patients, anterior translation was corrected more than rotation. Females had higher pre- and residual post-reconstruction internal rotation compared to males. When compared to adults, adolescents had increased internal rotation and total rotation both pre- and post-reconstruction.

### Introduction

The number of adolescents participating in sports continues to increase as 35 million children in the United States are currently involved in sporting activities.<sup>1</sup> Consequently, an increase in the number of sports-related injuries has also been seen as a result of higher participation rates as well as year-round focus on individual sports.<sup>2,3</sup> Children and adolescents are also competing at higher levels.<sup>2</sup> Shea *et al.* showed that knee injuries account-

ed for 22% of all sports injuries and anterior cruciate ligament (ACL) tears represented 31% of total knee injury claims in soccer players aged 5 to 18 years old.<sup>4</sup> In addition, 70% of hemarthroses in children were found to be due to sports injuries, and 63% of patients with hemarthroses have ACL tears.<sup>5</sup> ACL injury among children and adolescents is now a common injury being treated by orthopedic surgeons nationwide.<sup>2</sup>

Historically, children were instructed to delay ACL reconstruction until skeletal maturity due to the risk of physeal damage resulting in either longitudinal growth disturbance or varus/valgus angulation. However, nonoperative management of pediatric ACL injuries has led to poor results.<sup>6</sup> Studies have shown functional instability, increased risk of meniscal and chondral damage, reduced activity, and need for additional surgeries in patients initially treated nonoperatively.<sup>7-13</sup> A recent meta-analysis by Ramski *et al.* suggests that early operative treatment for pediatric ACL injuries is favored rather than delayed or nonoperative management.<sup>11</sup>

Children and adolescents are physiologically different compared to adults. When considering young athletes with ACL tears, this is a very unique patient population. Factors such as young age,<sup>14</sup> ligamentous laxity,<sup>15,16</sup> higher activity levels,<sup>17</sup> and presence of growth plate-related issues distinguish children from adults. It is important to acknowledge these differences when evaluating and treating young patients with ACL tears.

Computer navigation is increasingly being used in ACL reconstruction surgery. While outcomes following computer-assisted ACL reconstruction have not been found to be superior to traditional methods, computer navigation has been shown to increase the accuracy of bone tunnel placement compared to conventional arthroscopy.<sup>18-21</sup> In addition, computer navigation has been found to be a reliable way to describe rotational and translational stability patterns in adult patients.<sup>19,22</sup> However, no study has examined pre- and post- ACL reconstruction stability patterns specifically in the pediatric/adolescent population. The purpose of this study was to evaluate injury and ACL reconstruction stability measurements in adolescent patients who underwent computer-assisted ACL reconstruction and compare them to a larger adult cohort.

### Materials and Methods

This study was approved by the Institutional Review Board. It was a retrospective review of all adolescent patients (less than 18 years old) who underwent computer-assisted primary transphyseal single bundle ACL reconstruction

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by a single surgeon from 2007 to 2012. Exclusion criteria included revision surgeries and those patients with incomplete intraoperative data.

All patients had computer-navigated ACL reconstructions using the Aesculap 2.0 Ortho Pilot Navigation System® (B. Braun Aesculap, Tuttlingen, Germany). A diagnostic arthroscopy was performed in all patients and if meniscal pathology was present, this was addressed first. During ACL reconstruction, tibial and femoral transmitters were applied using 2.5 mm K-wires for navigation purposes. Appropriate landmarks were registered and kinematic dimensions were acquired by ranging the knee from 0-90 degrees of flexion. Knees were secured on a semi-rigid bolster at 30 degrees of flexion for stability testing, and this was performed by the senior surgeon in all cases. Maximum anterior translation (AT), external rotation (ER) and internal rotation (IR) were measured and recorded for all patients both pre- and post-reconstruction.

Patient charts were retrospectively reviewed for this intra-operative stability data as well as for relevant surgical details (graft type, fixation), patient characteristics (age, gender), and injury characteristics including mechanism and associated additional intraarticular injuries (meniscal tear, capsular tear, chondral injury). Pre and post-reconstruction stability measurements were analyzed along with patient/injury characteristics and surgical details, and adolescent stability data was com-

pared to a larger cohort of adult patients (18 years old or older). Pearson correlation coefficients, T-tests, and ANOVAs were used for statistical analysis with a significance level set at  $P < 0.05$  *a priori*.

## Results

Thirty adolescents were identified within a larger cohort that included 113 adult patients. The demographics of the adolescent patients are seen in Table 1. Sports injuries were most common, with football, basketball, and soccer being the most common mechanisms.

Graft type was variable among adolescent patients (Figure 1). There were no significant differences in post-reconstruction anterior translation or rotational stability among the different graft types. The average pre-reconstruction anterior translation was 14.4 mm (SD 3.6) and the average post-reconstruction was 4.7 mm (SD 2.5). Patients with additional intra-articular injuries were found to have significantly higher pre-reconstruction AT than patients without additional injuries (16.9 mm *versus* 12.9 mm,  $P=0.002$ ). Post-reconstruction, patients with additional injuries also had higher AT and this approached significance (5.82 mm *versus* 4.1 mm,  $P=0.07$ ).

The average percent correction of AT was 67.5% (SD 11.9) and this was significantly higher than the percent correction of IR or ER (25.9% and 17.8% respectively,  $P < 0.0001$ ). The percent correction for AT, ER, and total rotation did not differ significantly when adolescents were compared to adults. Female adolescents were found to have higher internal rotation than male adolescents both pre- (25.6° *versus* 21.7°,  $P=0.026$ ) and post-reconstruction (20.1° *versus* 15.1°,  $P=0.005$ ). There were no statistical differences between males and females with regards to AT or ER. A comparison between adolescent and adult pre- and post-reconstruction measurements are summarized in Table 2. Compared to the adult cohort data, adolescents demonstrated significantly greater IR both pre- ( $P=0.047$ ) and post-reconstruction ( $P=0.003$ ), and tended to have less correction of IR (25.9% *vs* 32.7%,  $P=0.055$ ). Adolescents also had significantly greater total rotation both pre- ( $P=0.02$ ) and post-reconstruction ( $P=0.005$ ) when compared to adults.

## Discussion

This is the first study reporting pre- and post-operative knee stability measurements in adolescent patients undergoing ACL reconstruction. The most important findings in this study were that single bundle reconstructions

in adolescents corrected anterior translation significantly more than rotation. Also, female adolescents were found to have higher pre- and post-operative internal rotation when compared to male adolescents. When comparing adolescents to adults, adolescent patients demonstrated significantly greater amounts of internal and total rotation both pre- and post-reconstruction.

An ACL injury has been shown to have a significant effect on the quality of life in young patients. Some adolescents have a strong athletic identity, where a significant component of their overall sense of self-worth depends on sports participation. Adjusting to and coping

with injury may contribute to self-esteem and identity issues.<sup>23</sup> Quality of life measures have also been significantly linked to ACL surgery outcomes with regards to physical, emotional and social functioning.<sup>24</sup> In addition, subtle changes in knee mechanics may lead patients to have trouble getting back to a pre-injury state and this may lead to psycho-social complications.

ACL reconstructed surgical patients have a greater likelihood of returning to play at their pre-injury ability compared to non-operatively managed patients.<sup>11,25</sup> However, current return to sport rates in reconstructed patients are still far from perfect. A meta-analysis in 2002 on

**Table 1. Adolescent demographics (n=30).**

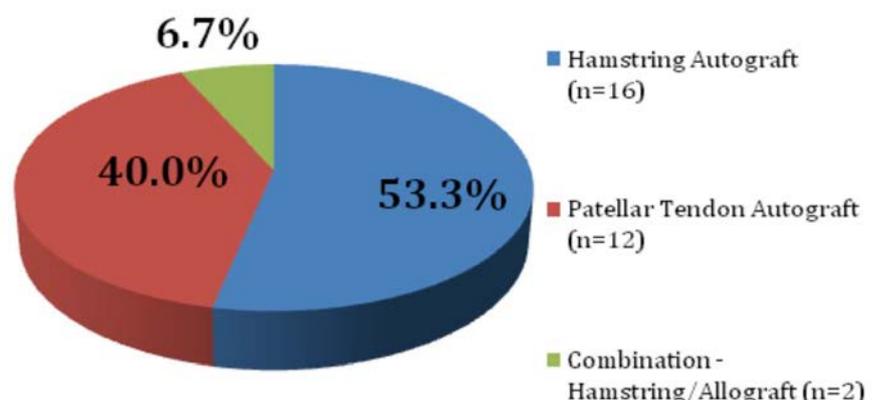
Patient	Injury characteristics
Average age	15.8 (SD 3.3)
Male / Female	18 (60%) / 12 (40%)
Isolated ACL tear	19 (63.3%)
ACL tear + additional intraarticular injuries	11 (36.7%)

ACL, anterior cruciate ligament.

**Table 2. Intraoperative stability measurements comparing adolescents and adults.**

Stability measurements	Adolescents	Adults	P
Pre-reconstruction AT (mm)	14.4	14.5	0.9
Post-reconstruction AT (mm)	4.7	4.8	0.85
Pre-reconstruction IR (°)	23.3	21.5	0.047*
Post-reconstruction IR (°)	17.1	14.4	0.003*
Pre-reconstruction ER (°)	17.7	16.9	0.35
Post-reconstruction ER (°)	14.5	14.2	0.75
Pre-reconstruction total rotation (°)	40.9	38.4	0.02*
Post-reconstruction total rotation (°)	31.6	28.7	0.005*

\*Significant values. AT, anterior translation; IR, internal rotation; ER, external rotation.



**Figure 1. Adolescent graft type distribution.**

return to play determined that 82% of ACL reconstructed patients returned to sports participation, but only 63% returned at their preinjury level.<sup>26</sup> More recent data has shown rates of return to preinjury levels of play are still not as high as would be expected.<sup>27-29</sup> It is possible that subtle rotational laxity could contribute to decreased functional abilities and lead to poor performance and inability to return to pre-injury levels of activity.

Aldrain *et al.* studied gender differences following computer navigated single *versus* double bundle ACL reconstruction.<sup>30</sup> Fifty-five adult patients were retrospectively reviewed after 2 year follow up. Female patients were found to have significantly greater internal rotation in both the single bundle and the double bundle groups than males. The greater degree of internal rotation in females was consistent with our data. Our results do not explain why female adolescents have more internal rotation laxity. Previously described reasons for varied female outcomes include anatomic,<sup>31-33</sup> kinematic,<sup>34</sup> and hormonal differences.<sup>35</sup> Hamstring autografts have also been found to have increased graft laxity in female patients following single bundle reconstructions.<sup>36,37</sup> The clinical significance of these gender differences has yet to be fully understood.

Anterior to posterior stability and rotational stability is achieved immediately after ACL reconstruction, however there is some evidence that deficient secondary restraint tissue in the ACL-deficient knee may influence post-operative laxity.<sup>19</sup> Adolescents in our study had significantly greater internal rotation and total rotation both pre- and post-reconstruction compared to adults. This may be due to the amount of stability from extra-articular stabilizers around the knee joint, possibly attributable to size and strength of musculature, which is likely decreased in adolescents when compared to adults. A large-scale study recently found young age (15-19 years old) to be a significant risk factor for revision ACL reconstruction.<sup>38</sup> It is plausible that increased rotation following ACL reconstruction in younger patients may be a contributing factor to failure, but this relationship needs to be further studied and delineated in the literature.

Perhaps treatment of the kinematic differences between adolescents and adults and males and females should be approached on a more individualized basis. For example, double bundle ACL reconstructions have been shown to control rotational stability more than single bundle techniques through improvement in pivot shift.<sup>30</sup> In addition, Kim *et al.* concluded that patients with more joint laxity may benefit more from a bone-patellar tendon-bone graft rather than quadrupled hamstring graft.<sup>15</sup> In this study, we did not observe any differences in laxity or rotation among the different graft

types used. While various techniques may currently exist to control for individual stability variations particularly with regards to rotation, it will first be important to determine the clinical significance of these subtle stability differences as they relate to both age and gender. Future research should be directed towards determining whether surgical technique should be individualized, based on a pre-operative stability profile.

There were limitations to this study. First, all surgeries were performed by a single surgeon at one institution. As a result, sample size was limited, however this also allowed us to control for differences in technique that commonly varies among surgeons. Graft type was variable in this study, however, we did not observe any significant stability differences between grafts. In addition, all adolescents in this study were nearing skeletal maturity and underwent transphyseal reconstructions, so differences in physeal sparing techniques were not assessed. This study was also retrospective and analyzed previously obtained values. Patient clinical outcome was not assessed within the scope of this study. The purpose of this study was to look at pre- and immediate post-reconstruction stability characteristics among adolescents. Future studies are indicated to evaluate how stability differences may affect clinical outcomes. Surgical techniques that allow for better correction of rotation in adolescent ACL reconstructions should also be considered.

## Conclusions

Anterior translation was corrected more than rotation with a single bundle transphyseal ACL reconstruction in adolescent patients. Female adolescents were found to have higher pre- and residual post-reconstruction internal rotation compared to male adolescents. When compared to adults, adolescents had increased internal rotation and total rotation both pre- and post-reconstruction. The results of this study suggest that unique kinematic differences exist among adolescent patients and different genders undergoing ACL reconstructions. Future research should be directed towards further defining these differences as they relate to both age and gender, as well as determining the clinical significance of these stability differences and whether certain surgical techniques may be more suited for an adolescent population.

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