LONGITUDINAL CHANGES IN MUSCLE STRENGTH, FLEXIBILITY AND KNEE LAXITY DURING PUBERTY IN GIRLS

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INTRODUCTION

From the onset of puberty, females are at a greater risk of sustaining a non-contact anterior cruciate ligament (ACL) rupture than males [1]. One factor commonly associated with greater ACL injury risk is increased passive knee laxity and the accompanying decrease in knee joint stability [2]. Females tend to display fluctuations in knee laxity across the menstrual cycle [3] as well as greater anterior knee laxity compared to their male counterparts [2]. However, how knee laxity changes at the onset of puberty and throughout the adolescent growth spurt is relatively unknown.

Rapid and differential timing of segment growth around the time of peak height velocity (PHV; peak growth in height) alters the moment of inertia of an individual’s limbs, in turn, requiring greater strength to perform movement tasks [4]. Although boys display a defined ‘spurt’ in the development of quadriceps strength after PHV, this trend is not apparent in girls [5]. As the hamstring muscles work in synergy with the ACL by imparting a posterior drawer force to the tibia [6], any changes in hamstring strength during the growth spurt are vital to understand risk factors for ACL injuries in this adolescent population. Therefore, this study aimed to investigate changes in lower limb muscular strength, flexibility and anterior knee laxity throughout the adolescent growth spurt in pubescent girls, with implications for ACL injuries.

METHODS

Thirty-five healthy girls (10-13 years), confirmed as Tanner Stage II of pubertal development [7] and 4-6 months from their PHV, determined using a gender-specific multiple regression equation [8], volunteered to participate in the study. Participants were tested in the laboratory four times over 12 months, based around the timing of their PHV (Figure 1). Each participant’s height and mass were also tracked monthly in their homes to determine the precise timing of their PHV.

During each laboratory testing session, participant height, mass and lower limb anthropometrics were measured. Passive anterior knee laxity was quantified for each participant’s dominant lower limb using the Dynamic Cruciate Tester (DCT; Smith & Nephews Richards, Australia), with the knee flexed between 20-30° [2]. Force (N)/displacement (mm) curves were plotted to determine changes in knee laxity throughout the growth spurt. Goniometric measurements of the knee and hip were also performed to determine changes in flexibility of the hamstrings, quadriceps and iliopsoas muscles over time. Concentric and eccentric strength of the quadriceps and hamstring muscles were assessed using an isokinetic dynamometer (KinCom, Chattanooga Inc., USA) at 180°.s⁻¹. Peak torque was recorded and normalized to body mass (Nm.kg⁻¹) to determine changes in lower limb strength throughout the growth spurt.

A linear mixed model design was used to determine any significant ($p \leq 0.05$) main effects of time on the dependent variables, controlling for growth variables as covariates. Post-hoc comparisons were performed using a $t$-test with a Bonferroni adjustment.

RESULTS AND DISCUSSION

A significant main effect of time ($p < 0.001$) on PHV was found, such that the participants grew significantly faster during Test 2 compared to the other test sessions (Figure 1). Although the participants were growing more rapidly at the time of Test 2, no significant main effect of time on iliopsoas ($p = 0.302$) or quadriceps ($p = 0.394$)
flexibility was evident. However, a significant ($p = 0.05$) increase in hamstring flexibility was found from Test 1 to 4.

A significant ($p = 0.005$) main effect of time on passive knee laxity was displayed. Post-hoc analyses revealed a significant increase in passive knee laxity from Test 1 to 2 ($p = 0.008$), as well as from Test 1 to 3 ($p = 0.046$; Figure 1). It is postulated that greater knee joint laxity may lead to a decrease in knee joint stability, increasing the likelihood of rupture [2]. This suggests that girls may be at an increased risk of ACL injury at the time they are experiencing their PHV.

![Figure 1](image_url): Means ± SE for peak height velocity (PHV) and passive knee laxity over 12 months.

The participants displayed no change in either concentric or eccentric hamstring strength over time (Table 1). However, a significant effect of time on concentric quadriceps strength was evident, whereby post-hoc analyses revealed a significant strength increase from Test 1 to 4 (Table 1). Contracting the quadriceps during dynamic movements increases anterior tibial translation, placing greater strain on the ACL. We speculate that, during the adolescent growth spurt, the hamstring muscles might be less proficient when acting synergistically with the ACL against the stronger quadriceps contractions when performing dynamic movements. This may potentially place girls at a greater risk of sustaining an ACL injury during the adolescent growth spurt, although further research is warranted to support this notion.

**CONCLUSIONS**

From the time of PHV participants displayed significantly increased passive knee laxity accompanied by a significant increase in quadriceps strength over time, with no subsequent increase in hamstring strength. It is postulated that this strength imbalance combined with increased knee laxity may increase the risk of ACL injury at the time of PHV.

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**REFERENCES**


<table>
<thead>
<tr>
<th>Torque (Nm.kg⁻¹)</th>
<th>Test 1 (n = 22)</th>
<th>Test 2 (n = 35)</th>
<th>Test 3 (n = 32)</th>
<th>Test 4 (n = 16)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric hamstring</td>
<td>0.779 ± 0.054</td>
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<td>0.759 ± 0.044</td>
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<tr>
<td>Eccentric hamstring</td>
<td>1.476 ± 0.077</td>
<td>1.290 ± 0.063</td>
<td>1.261 ± 0.066</td>
<td>1.292 ± 0.088</td>
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<tr>
<td>Concentric quadriceps</td>
<td>0.953 ± 0.062</td>
<td>0.995 ± 0.051</td>
<td>1.086 ± 0.054</td>
<td>1.181 ± 0.072</td>
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<tr>
<td>Eccentric quadriceps</td>
<td>2.239 ± 0.117</td>
<td>2.047 ± 0.096</td>
<td>2.042 ± 0.101</td>
<td>2.315 ± 0.138</td>
<td>0.142</td>
</tr>
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*Significant increase in strength from Test 1 to 4 ($p = 0.05$).