Physiological Knee Laxity During Pubertal Growth

Francesco Falciglia, M.D., Vincenzo Guzzanti, M.D., Vincenzo Di Ciommo, M.D., and Alessia Poggiaroni, M.D.

Abstract

Background: The relationship of physiologic laxity to age has been reported in only cross-sectional studies. The current investigators suggest further investigations, to include Tanner staging in order to understand the extent to which increases in maturity influence alterations in laxity.

Materials and Methods: A two-phase (cross-sectional and longitudinal) study assessed knee joint laxity and flexibility in 172 normal adolescents, using a KT 2000 arthrometer, anthropometric measurements, and Carter and Wilkinson tests. Correlation of these evaluations was done with gender and Tanner stage. Data from clinical and KT 2000 measurements at the initial evaluation were analyzed as the cross-sectional, single assessment phase of the study. The longitudinal phase of the study reviewed modulation of laxity and flexibility, with growth by repeated examination of the above tests in individual subjects during their adolescent growth phase.

Results: Increased flexibility was seen significantly more frequently in females than males in both study phases. Age, Tanner stage, and anthropometric values were not significantly associated with laxity in the cross-sectional study. In the longitudinal study, an inverse relationship was demonstrated between Tanner stage and KT 2000 laxity measures after adjusting for other variables. Sequential evaluation showed a progressive decrease of sagittal laxity at the onset of Tanner stage 2. Laxity was significantly greater in adolescents, with signs of joint physiologic hyperflexibility.

Conclusion: Evaluation of laxity and flexibility during the adolescent growth phase is important for better definition of muscle strengthening or flexibility programs, to avoid functional overloads and injury.

Physiological movement at each joint is determined by joint surface relationships, and capsular, ligamentous, and periarticular musculotendinous structures. When a joint is actively or passively stressed in its plane of movement, joint surfaces contact, and this contact is maintained by joint congruity, tension within the capsular-ligamentous structures, and musculotendinous unit activity.

We consider physiological flexibility to be a joint property that allows normal planes of articular movement. Physiological joint laxity, on the other hand, is that characteristic which makes it possible to move the joint using direct force in such a way that it alters normal physiological articular contact. Although laxity and flexibility influence each other, one must consider these terms as different from one another. The amount of physiologic joint laxity, even if articular contact is maintained, influences articular excursion in the normal plane of movement.

Several investigators assessed, in actuality, articular flexibility but described it as laxity,2,9 mobility, or hypermobility.10-17 All methods of current study of flexibility are based on articular excursions in normal planes of movement.

The most widely used clinical assessment of flexibility was described by Carter and Wilkinson and uses five passive motion tests.2 Most investigators agree that joint flexibility diminishes as age increases.4,6,7,16,18,19 Only 5% to 10% of the population maintains a high degree of joint flexibility in adulthood.4,5,13,16

Physiological laxity of the knee in the sagittal plane has been evaluated using arthrometers (Genucom, KT-1000, KT 2000) which, by applying specific forces, measure move-
The relationship of sagittal plane physiologic laxity and maturational age has been reported in cross-sectional studies by Baxter and Flynn and colleagues. These investigators observed a reduction of sagittal laxity as age increased and suggested further investigations were advisable, to include Tanner staging in order to understand the extent to which increases in maturity influence alterations in laxity.

The current study attempts to elucidate the relationship between flexibility and laxity in relation to other factors, including gender, Tanner stage, and anthropometric measures. We used a two-phase analysis of normal children, including a single examination cross-sectional model and a longitudinal series with repeat examinations of individual patients during their adolescent growth phase.

Materials and Methods

Normal preadolescent and adolescent student volunteer subjects without a history of knee injury were recruited and examined. Informed consent and permission was obtained from subjects' parents prior to entering the study. Clinical anthropometric values recorded were weight, height, length of the lower limbs, and thigh diameter. Tanner stage and Carter and Wilkinson tests were also determined (Fig. 1). Carter and Wilkinson tests were considered positive if: 1. the thumb, when passively stressed to the flexor surface of the forearm, comes into contact with the forearm skin; 2. the fingers, when passively stressed in hyperextension, become parallel to the extensor surface of the forearm; 3. passive hyperextension of the elbow exceeded 10°; 4. passive hypertension of the knee exceeded 10°; and, 5. dorsiflexion of the ankle with pronation of the foot reached 45°. A positive response to three of the five tests was regarded by the original investigators as an index of “hyperlaxity,” however, it would be more accurate to term this response hyperflexibility.

Sagittal plane laxity of both knees was determined using standardized KT 2000 techniques, with a force of 13.5 Kg (134 N) (Fig. 2). Measurements were gathered independently by two observers. We used the average of these side-to-side measurements, since no statistical difference (paired t-test) was found between results of the two observers.

For the longitudinal phase of the study, subjects were serially evaluated by identical methods and the same observers over a two-and-one-half year period, with a minimum of three and a maximum of five observations at planned intervals of 6 months.

Chi-square and the Student t-test were used as required. Multiple regression analysis calculated the relationship of KT 2000 measurements from initial observations in the cross-sectional study. For the longitudinal study, repeated measures of a mixed-effect model (fixed and random effects) were analyzed using a (S-plus) software package. Statistical significance was considered to be p < 0.05.

Results

The initial study cohort consisted of 172 subjects, 92 boys, and 80 girls (10.5 to 14.5 years; average, 12.1 years; sd, 0.93). Since the subjects were of varying maturity at the initiation of the study, data from 49 subjects who were almost or fully mature were used in only the cross-sectional phase of the study. The remaining data on 123 immature subjects, 62 boys and 61 girls (10.5 to 14.5 years; average, 12.2 years; sd, 0.92) represent the cohort for the longitudinal study.

Cross-Sectional Survey

Variability among individuals was studied using bilateral single measurements for each test of each subject. Analysis of the initial observations showed normal distributions of observed measurements, without statistically significant differences between males and females and left and right sides (Table 1, Fig. 3).

When overall Tanner pubertal stages were taken into ac-
count, an inverse correlation was seen, i.e., with advancing Tanner stage, diminishing laxity (Fig. 4). When individual Tanner stages were analyzed, we found a slight increase in laxity between stage 1 and stage 2 and then decreases in laxity in both genders, with the decrease more marked males (Fig. 5). Age, Tanner stages, and anthropometric clinical measurements were tested for correlation with laxity. No significant predictor of laxity was noted among the variables using a multiple regression model.

Generalized ligamentous flexibility, defined as three or more positive tests of Carter and Wilkinson, was found in four males and 12 females and was significantly more frequent in females than in males (15% vs. 4%, p = 0.03). As expected, sagittal knee laxity was significantly higher in subjects with increased physiologic flexibility than in subjects with normal physiologic flexibility (5.64 vs. 4.15, p = 0.001).

**Longitudinal Survey**

This study cohort consisted of 123 subjects, who were observed on at least three consecutive occasions. The data set represents a compromise between follow-ups of 4 or 5 observations with fewer patients (70 or 37, respectively) and the vast majority of patients with three observations. The 70 patients in the longitudinal study significantly demonstrated the same inverse relationships between the KT arthrometer results and Tanner stage, as did the group with three observations.

In 15 subjects with increased flexibility by Carter-Wilkinson tests, three had no change in scores and remained with scores of 3 or 4. Three subjects had minimal changes, e.g., from 4 to 3 or 3 to 2. When the nine cases with at least three observations showing changes in Carter-Wilkerson scores from 4 or 3 to 1 or 0 were reviewed, three cases (all girls) had a rapid change from 3 to 0, with a change from a Tanner 1 to a Tanner II stage. Six of the nine children had a more gradual change to Carter-Wilkinson scores of 1 to 0 at Tanner stage 3, or stage 4 in five of the six subjects. All of these 9 children with significant changes of Carter-Wilkerson scores showed parallel decreases in KT scores as well. Six of the 15 subjects without significant changes in Carter-Wilkinson scores showed fewer changes in KT scores as well.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Laxity by Gender in 172 Subjects (Cross-Sectional Survey)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males (N = 92)</td>
</tr>
<tr>
<td>Age</td>
<td>Mean</td>
</tr>
<tr>
<td>KT Left knee</td>
<td>4.41</td>
</tr>
<tr>
<td>KT Right knee</td>
<td>4.25</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>48.60</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>154.01</td>
</tr>
<tr>
<td>Length left leg (cm)</td>
<td>81.4</td>
</tr>
<tr>
<td>Diameter left thigh (cm)</td>
<td>40.35</td>
</tr>
<tr>
<td>Length right leg (cm)</td>
<td>81.4</td>
</tr>
<tr>
<td>Diameter right thigh (cm)</td>
<td>40.72</td>
</tr>
</tbody>
</table>

SD: Standard Deviation; p = value of paired t-test.

Figure 3 Laxity (KT arthrometer) by gender in the cross sectional study of 172 subjects.

Figure 4 Tanner stages by gender in cross sectional study of 172 subjects.
When laxity was analyzed over time relative to gender and Tanner stage, we found Tanner stage a significant predictor of KT 2000 measurements \( (p = 0.03) \). This was due to the pronounced effect of Tanner stage 4, with diminution of translation to 0.92 mm after adjustments were made for gender and time (Fig. 6). Taking into account individual variability by multiple regression analysis, no significant predictor of laxity or flexibility was demonstrated in the cross sectional phase. In the longitudinal group, Tanner stage and gender were predictors of diminution of laxity.

**Discussion**

Flexibility and laxity are terms often used interchangeably. This is an error, since each term defines a different property. As shown in our study, flexibility and laxity are, however, quite inter-related. Modification in joint laxity and flexibility during growth and after skeletal maturity is attributable to physiological qualitative and quantitative alterations in collagen structure.\(^{19,24-26}\) Diminution in laxity and flexibility has been described on the increasing maturity of preadolescents and adolescents, with differences within groups observed.\(^{18,22}\)

Our longitudinal data confirm a progressive reduction in sagittal laxity as measured by a KT 2000 arthrometer during the rapid, peak height velocity of pubertal growth. Physiological laxity measures evaluated with a KT 2000 must be considered in relation to growth. In our adolescent population, we showed that variations in laxity are not correlated to anthropometric variables but rather, an inverse correlation with Tanner stage was found with modification by gender, that is, a different magnitude of laxity diminution was seen at various Tanner stages in males as opposed to females. We feel our longitudinal study data are more specific than the data of the cross-sectional study of Flynn and coworkers.\(^{22}\)

Clinical evaluation of the growing child must consider in which pubertal stage the most variability in joint laxity occurs. At Tanner stage I, alterations in flexibility and laxity are likely to occur. With increasing loss of flexibility and laxity, there is a change in tolerable physiological and biomechanical forces to intra-articular structures.\(^{2,9,23,27-33}\) Joint movement can decrease because of increased musculotendinous tightness and reduction in elasticity of the ligaments. If an imbalance in flexibility is created, increased functional overload is more likely to occur.\(^{1,23}\) Evaluation of laxity and flexibility during the adolescent growth phase is important for better definition of muscle strengthening or flexibility programs to avoid functional overloads in adolescents.

Literature reports describe an association between anterior knee pain, patellar instability, glenohumeral instability, and ankle sprains and patients with joint hyperflexibility or hypermobility.\(^{1,7,9,27-29,31-34}\) Hypermobility, or, more specifically, hyperflexibility of joints should be considered different from laxity. In our study, 4% of males and 15% of females in the adolescent population were found to be positive to at least three Carter-Wilknson tests and were considered to have physiological joint hyperflexibility or hypermobility. Knee sagittal laxity was significantly higher in subjects with this increased physiologic flexibility than in subjects with normal flexibility. In a significant percentage of children with initial hyperflexibility, normalization of flexibility occurred with progressive maturity.

We have shown that, during rapid adolescent growth, reduction in knee joint sagittal laxity and flexibility can be expected secondary to a complex interaction of rapid distal femoral and proximal tibial physeal growth, producing muscular and soft tissue increased tension about the knee. Growth characteristics are too variable during this period from subject to subject to identify, by a single, one-time assessment, a specific age when joint laxity changes. Single evaluations in our cross section study showed no significant association with anthropometric measurements or Tanner stage. Only sequential assessments of Tanner stage and laxity of individual subjects in the longitudinal study while accounting for gender differences identified the phases when variation in physiological laxity occurred.
follow-up, we saw a progressive decrease in sagittal plane knee laxity at the onset of Tanner stage 2. Laxity values were significantly higher in adolescents who showed clinical signs of joint physiological hyperflexibility.

**Disclosure Statement**

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

**References**