Introduction

Puberty is a period of transition from childhood to adulthood and is often viewed within the context of sexual maturation and statural growth. During and after puberty, human skeletal muscles undergo both structural and functional changes due to muscular, neuronal, hormonal and biomechanical factors (Blimkie, 1989), leading to an increase in physical performance. The majority of related studies have focused on changes in maximal voluntary strength (Seger & Thorstensson, 1994) or on the relationship between muscle strength and muscle or body size (Kanehisa et al., 1995). Changes in electrically evoked twitch contractile properties during puberty have been also well studied (Davis et al., 1983; Belanger & McComas, 1989; Pääsuke et al., 2000). However, mechanical properties of muscles in prepubertal children are poorly documented, notably concerning musculo-tendinous (MT) stiffness. A specific ankle ergometer has been developed to study the mechanical properties of the ankle rotators of prepubertal children (Pérot et al., 1999) and to analyze the elastic properties of the MT complex of the plantarflexors in prepubertal children, taking into account age of the children.

Methods

16 children were studied with ages ranging from 7 to 11 years. The children were seated on an adjustable seat with their left foot attached rigidly to an adjustable foothold, so that the horizontal bi-malleolar axis coincided with the axis of rotation of the actuator of the ergometer. The knee was extended to 110° and the ankle was placed to 90°, i.e. neutral position. The thigh was maintained by a restraint system in order to keep it immobilized. A full test session, including rest periods, lasted about approximately 1 hour and comprised: (i) an explanation of the test, (ii) preparation of the subject, (iii) familiarization to the test and (iv) the actual test.

In a first test, maximal voluntary contraction (MVC) was determined in plantarflexion under isometric conditions. Three trials were carried out and the best performance was considered as the true MVC of the day.

An index of MT stiffness was quantified by means of a quick-release technique derived from classical methods in isolated muscles (Goubel & Pertuzon, 1973). In the present experiment the quick-release method was adapted to measure musculo-tendinous stiffness of the plantarflexors. Quick-release movements from the neutral position were achieved by a sudden releasing of the moving parts of the device while the child maintained a submaximal isometric torque in plantarflexion. Three trials were performed at 25%, 50% and 75% of MVC. For each quick-release trial the collected parameters were the isometric torque before the release and angular displacement. Then, MT characteristics were determined at the beginning of the movement, i.e. when the elastic elements are supposed to recoil. Their stiffness was calculated as the ratio between variations in angular acceleration (as a double derivate of angular displacement) and angular displacement, multiplied by the corresponding inertia value. MT stiffness values were related to the corresponding isometric torque initially exerted by the child. This isometric torque was calculated as a mean amplitude during the 200 ms preceding the quick-release movement. The slope of the linear stiffness-torque relationship so obtained was defined as a stiffness index of the MT complex ($SI_{MT}$). Furthermore, taking $SI_{MT}$ has the advantage to be independent of the required torque level and to avoid the use of MVC or cross-sectional area measurements for normalizing MT stiffness (Lambertz et al., 2001).
Moreover, electromyograms (EMG) were detected on each part of the triceps surae (TS), i.e. the soleus (Sol), the gastrocnemius lateralis (GL) and gastrocnemius medialis (GM) using standard Ag/AgCl surface electrodes. The electrodes were placed over the belly of each gastrocnemius muscle, for the soleus 2 cm below the insertion of the gastrocnemii, and the ground electrode was placed over the tibia. EMG signals were recorded differentially, amplified, and band-pass filtered (1 Hz and 1 kHz) before storage. Then, EMGs were full wave rectified and summed up in order to quantify TS background activity (BGR). BGR was expressed as a mean amplitude during the 200 ms isometric phase just before the quick-release movement. Furthermore, three to five supramaximal electrical stimulations were achieved in order to get the maximal motor direct response (M_max). The mean amplitude of the TS M_max (\( \bar{M}_{\text{max}} \)) expressed by the ratio between duration and area, was used to normalize BGR.

**Statistics**

Statistical analysis included linear regression analysis to test stiffness-torque, stiffness-BGR relationships, as well as mean stiffness index between age groups. Mean values are represented as mean ± SEM. A level of P<0.05 was selected to indicate statistical significance.

**Results & Discussion**

Concerning the musculo-tendinous system, figure 1A and 1B illustrates typical stiffness-torque and stiffness-BGR relationships, respectively. As one can see MT stiffness increased gradually when increasing the instruction torque. This was also true when using normalized BGR data. Best fit was always a linear regression whatever the used independent parameter (torque of normalized BGR).

![Fig. 1](image)

Fig. 1 Typical experimental data from quick-release tests for two children (7 years, open circles; 11 years, filled circles). In A MT stiffness was related to the isometric torque. The slope for the 7 year old child was 2.89 (r=0.96; P<0.05) and for the 11 year old child 1.59 (r=0.93, P<0.05). In B MT stiffness was related to the normalized The slope for the 7 year old child was 10.85 (r=0.85; P<0.05) and for the 11 year old child 19.43 (r=0.92, P<0.05).

Preliminary data obtained in 16 children showed a decrease in mean \( S_{MT} \) ranging from 2.17 ± 0.09 to 1.74 ± 0.38 rad\(^{-1}\) for the youngest to the oldest age group. Relating \( S_{MT} \) to age led to a significant decrease (Fig. 2A). This result seems to be paradoxical, knowing that \( S_{MT} \) of adults is about 3.5 rad\(^{-1}\) (Lambertz et al., 2001). Thus, it is unlikely that MT stiffness decreased with age in prepubertal children in order to increase afterwards. Interestingly, when relating MT stiffness to normalized BGR, this new index of MT stiffness was found to increase with age. More precisely, mean values of this index of MT stiffness increased from 10.69 ± 6.51N m rad\(^{-1}\) to 15.30 ± 6.53 N m rad\(^{-1}\) for the youngest to the oldest age group. Then, relating the mean MT stiffness indexes to age led to a significant increase (Fig. 2B).
In the present study, we reported, for the first time, age related changes in the elastic properties of the MT complex in prepubertal children. The most unexpected and interesting point to emerge from this study was that MT stiffness indexes showed to different evolution when expressed by torque or by activation data. It can be hypothesized that MT stiffness depends on the activation patterns of prepubertal children in order to maintain the demanded instruction torque. This hypothesis was also put forward by others. Pääsuke et al. (2000) reported that ankle plantarflexors of prepubertal boys exhibit higher twitch to MVC force ratios compared to postpubertal boys and men. This fact indicates that an increase in isometric voluntary muscle strength during and after puberty is associated with an increase in motor unit activation patterns under maximal conditions. This result is also in agreement with Blimkie (1989), who found that postpubertal boys could voluntarily activate a greater percentage of their available motor units during MVC than prepubertal boys. As reported by Belanger & McComas (1989), young children are not able to voluntary activate their motoneurone pool optimally, and thus, a full motor unit activation is not achieved. Then, young prepubertal children should over activate their motoneurone pool when maintaining a submaximal isometric torque. Consequently, they present a higher MT stiffness compared with their older counterparts.

In conclusion, this preliminary study demonstrated that the elastic properties of the MT complex is affected by the activation capacities of prepubertal children. Further studies, including the quantification of such a failure in voluntary activation capacities is now in progress. Moreover, the population inside each age group should be increased in order to account for better statistical results in mean values.

References