SHEAR STRENGTH OF THE PROXIMAL TIBIAL TUBEROSITY'S CARTILAGE BRIDGE

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ABSTRACT

Shear properties of 24 beam samples of the tibial tuberosity growth plate were compared by direction of shear testing and by age in 4-5 month old and 12-18 month old calves. Ultimate shear stress of the tuberosity was 28% larger and shear modulus was 46% larger for downward than for upward shear of the tuberosity, regardless of age; ultimate shear stress, considering both directions of testing, was 46% greater and shear modulus 40% greater in the 12-18 month than in the 4-5 month group. Ultimate strain was not different by either age or shear direction and averaged 48% (SD 12). Growth plate thickness was 78% greater in the younger age group: 4.10 mm (SD 0.78) compared with 2.30 mm (SD 1.14).

INTRODUCTION

In the immature tibia, the tibial tuberosity lies anterior to the proximal tibial epiphysis from which it is separated by an epiphyseal plate, which runs perpendicular to the proximal tibial epiphyseal plate and merges with the articular cartilage in the knee joint (Fig. 1). This growth plate has been sometimes referred to as a cartilage "bridge" [1] and it is a bipolar growth plate since growth and bone formation occur on both the tuberosity and epiphyseal sides of the plate. We hypothesized that this cartilage bridge would be particularly resistant to shear stress due to the expected tension in the patellar tendon, which inserts into the tuberosity. To test this hypothesis, we compared two different directions of shear, one related to an upward directed force on the tuberosity and the other to a downward force. We also examined the effect of maturation of the cartilage bridge by comparing the shear properties of 4-month-old with 12-18 month old calves.

MATERIALS AND METHODS

Eight stifle joints were obtained from 12-18 month old and four stifle joints from 4-5 month old calves and stored at –20 degrees Celsius. Two beams of bone-cartilage-bone were prepared with a diamond saw at 100 rpm, using buffered saline irrigation, from medial and lateral positions in each tibia, yielding 24 beams in total. The beams were 7 x 7 mm in cross section and consisted of proximal tibial

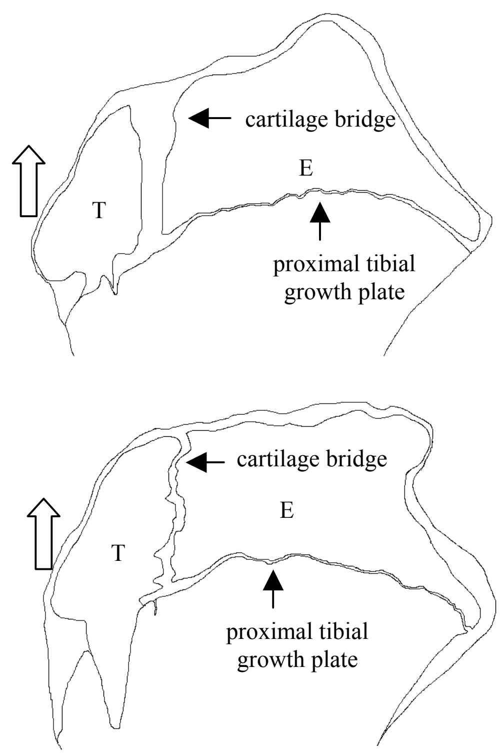

Figure 1. Sagittal section of a 4-month (top) and 18-month (bottom) old proximal tibia. The tibial tuberosity (T) is anterior to and separated from the proximal tibial epiphysis (E) by the cartilage "bridge." Open arrows show patellar tendon force pulling up on anterior aspect of tuberosity.

epiphyseal bone, growth cartilage, and the tuberosity. Orientations were carefully marked on each beam. Alizarin Red S was used to stain mineralized tissue and to enable growth plate thickness to be measured by microscopy to the nearest 0.05 mm on all four sides of each beam. Beam cross-sectional dimensions were measured by micrometer to 0.001 mm on both sides of the growth cartilage and averaged to obtain growth cartilage cross-sectional dimensions.

The medial and the lateral beams of each pair were randomly assigned to be sheared by either displacing the tuberosity in the upward direction, parallel to the bridge, or in the downward direction, parallel to the bridge. Each beam was secured in a shear jig by gripping as close to the growth plate as possible [2]. The shear jig was mounted to an x-translation table to allow antero-posterior motion during upward or downward shear at 0.004 mm/sec. A Sintech 5/G materials testing machine (MTS, Eden Prairie, MN) was used with a +/- 1,000-N load cell (precision 0.1-0.8 N). Crosshead displacement was monitored with an optical encoder to the nearest 0.001-mm and was corrected for system compliance. Ultimate stress was defined as the maximum shear load divided by the cross-sectional area of the beam and ultimate strain as the strain at ultimate stress. The shear modulus was defined as the tangent modulus of the steepest portion of the stress-strain curve.

Multivariate analysis of variance (manova) was employed using Pillai's trace to compare the following dependent variables: ultimate stress, ultimate strain, shear modulus, and growth plate thickness. The independent variables were: The direction-of-testing, age group, and subject ID served as a random blocking factor, which was nested in the age group. Manova testing was followed by univariate analyses of variance for each independent variable.

RESULTS

The dependent variables differed by shear direction ($p = 0.01$), and age ($p = 0.03$) (Manova). Contrary to our hypothesis, the shear direction corresponding to pulling up on the tuberosity had lower shear strength ($p = 0.01$) and modulus ($p = 0.001$) than shear in the opposite direction (Tables 1&2). Maturation resulted in a greater shear strength ($p = 0.001$) and modulus ($p = 0.01$) at 12-18 months than at 5 months. Ultimate strain was not different by either age ($p = 0.35$) or shear direction ($p = 1$) and averaged 48 % (SD 12, n = 24).

Growth plate thickness was 78 % greater in the younger age group: 4.10 mm (SD 0.78, n = 16) compared with 2.30 mm (SD 1.14, n = 8) ($p = 0.01$). The linear regression between ultimate stress and growth plate thickness for all shear tests in which the cartilage bridge was sheared by pulling up on the tuberosity was: ultimate stress (MPa) = 2.25 – 0.26 growth plate thickness (mm) ($R^2 = 0.47$, $p = 0.008$, n = 12). For the reverse direction it was: ultimate stress (MPa) = 2.72 – 0.27 growth plate thickness (mm) ($R^2 = 0.66$, $p = 0.0008$, n = 12).

There were no statistically significant interactions between age and direction of shear ($p = 0.57$). This implied that ultimate shear stress of the tuberosity was 28% larger and shear modulus was 46% larger for downward than for upward shear, regardless of age; and that ultimate shear stress was 46% greater and shear modulus 40% greater in the 12-18 month than in the 4-5 month group, regardless of direction of testing.

DISCUSSION AND CONCLUSIONS

By 18 months, the 'cartilage bridge' had thinned considerably. This coincided with an increase in shear strength and modulus. The directional differences in both shear modulus and ultimate stress may be related to the insertion site of the patellar tendon being at the anterior and inferior aspect of the tuberosity. Tension transmitted through the anterior bands of the patellar tendon on this anterior and inferior end of the tuberosity could cause the proximal and posterior end to rotate posteriorly and inferiorly, creating a downward shearing force on the tibial epiphysis.

Table 1. Mean (Standard Deviation) of Microstructural Shear Properties of Proximal Tuberosity's Cartilage Bridge in 4-5 Month Old Calves (n = 4 Per Cell)

	Upward Force on Tuberosity	Downward Force on Tuberosity
Ultimate Shear Stress (MPa)	1.13 (0.17)	1.55 (0.32)
Shear Modulus (MPa)	2.74 (0.24)	4.65 (1.41)

Table 2. Mean (Standard Deviation) of Microstructural Shear Properties of Proximal Tuberosity's Cartilage Bridge in 12-18 Month Old Calves (n = 8 Per Cell)

	Upward Force on Tuberosity	Downward Force on Tuberosity
Ultimate Shear Stress (MPa)	1.82 (0.46)	2.10 (0.45)
Shear Modulus (MPa)	4.74 (0.93)	5.62 (1.30)

Table 3. Mean (Standard Deviation) of Microstructural Shear Properties of Growth Plates from the Proximal Tuberosity's Cartilage Bridge and Proximal Tibial Epiphysis of 12-18 Month Old Calves

	Tuberosity *	Proximal Epiphysis [2]
Growth Plate Thickness (mm)	2.30 (1.14)	0.59 (0.12)
Ultimate Shear Stress (MPa)	1.96 (0.45)	2.20 (0.64)
Ultimate Shear Strain (%)	48 (12)	95 (23)
Shear Modulus (MPa)	5.18 (1.15)	3.22 (1.01)

*Averaged over both directions of shear

These mechanical properties have clinical relevance in relation to Type 2 tibial tuberosity fractures, which are compression-impaction injuries in which the entire tuberosity is separated from the tibial epiphysis [1].

These results for the tuberosity's cartilage "bridge" may be compared with shear properties of the proximal tibial epiphyseal plate of a 12-18 month old calf (Table 3). Compared to the proximal tibial physis, the growth plate of the tibial tuberosity was about 4 times thicker, the ultimate shear stress was similar, while ultimate shear strain was half as great and the tangent modulus was about 1.6 times greater.

REFERENCES

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