MICROSTRUCTURAL TENSILE PROPERTIES OF TWO DIFFERENT GROWTH PLATES IN THE PROXIMAL FEMORA OF CALVES: A MECHANICAL AND HISTOLOGICAL COMPARISON

Aakash A. Shah (1), John L. Williams (1), James J. Hamilton(1), Russell M. Fiorella (2), Aakash R. Amin (1)

(1) Department of Orthopaedic Surgery
University of Missouri–Kansas City
Kansas City, MO

(2) Department of Pathology
University of Missouri–Kansas City
Kansas City, MO

ABSTRACT

Microstructural tensile properties were obtained from the growth plates in the femoral head and greater trochanter of ten five-month old calf femora. Histological measurements were also obtained of the total growth plate thickness and the reserve zone thickness. This is the first study to directly compare microstructural tensile properties of different growth plates in the same bone. Samples from the two different growth plates had similar mechanical properties, despite large differences in growth plate and reserve zone thicknesses.

INTRODUCTION

In previous studies, the tensile strength of growth plate cartilage microstructures was shown to vary with location within a given growth plate, with growth plate thickness, and with collagen content [1,2]. In the present study we compared the strength and microstructure of growth cartilage from two different growth plates (capital femoral and greater trochanter) in the proximal femora of five-month old calves.

MATERIALS AND METHODS

Ten bovine femora were obtained from ten five-month old calves and stored in plastic bags at –20 °C. Using a handsaw, we excised two large 25 x 25 x 50-mm blocks from each of the capital and greater trochanteric growth plates. The blocks were oriented so that the heights were perpendicular to the growth plate and included both epiphyseal and metaphyseal bone on either side of the growth cartilage. Using a low speed saw with a diamond blade, we prepared smaller blocks of 2.5 mm (medial-lateral) x 15 mm (anterior-posterior) x 20 mm (superior-inferior) of bone-cartilage-bone. Then two consecutive 0.5-mm thick slices were cut from the medial ends of each of these blocks. Two samples were isolated from the greater trochanter and two from the femoral head of each of the 10 femora obtained from 10 animals (Fig. 1).

Samples were stained with Alizarin Red S to distinguish calcified matrix and bone from cartilage. Total growth plate thickness, reserve zone thickness and sample width were measured to the nearest 0.01-mm using a light microscope, with a calibrated reticle. The slice thickness was measured with a micrometer to the nearest 0.001 mm.

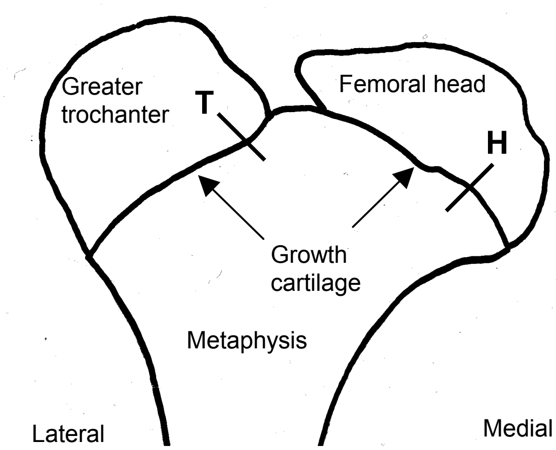

Figure 1. Tracing of a Radiograph of a 2-cm Coronal Section of Five-Month Old Calf Proximal Femur. Locations of the 0.5-mm Thick Slices of Greater Trochanter (T) and Capital Femoral Head (H) are Shown.

Samples were mounted in tensile grips [2] as close to the growth cartilage as possible, and tested to failure using a Sintech 5/G materials testing machine (MTS, Eden Prairie, MN). Tensile testing was performed at 0.004 mm/sec with Testworks 3.10 (MTS) to measure ultimate stress, strain and tangent modulus. Tangent modulus was defined as the slope of the steepest portion of the stress-strain curve, ultimate stress as the maximum stress attained and ultimate strain as the strain associated with ultimate stress. The load cell (Model SPI-3, Interface) range was ±13 N, with a sensitivity of 0.001 to 0.02 N. We assigned a zero value for the elongation at 0.5 N and calculated axial strains using a finite deformation formulation for strain [1]. Displacement was measured at the grips with an LVDT (Schaevitz HR200) with a range of ± 5 mm and sensitivity of 0.005 mm.

We calculated the means for the results of the consecutive slices taken from each location in a single animal and used the mean values for statistical analysis. A multivariate analysis of variance (manova) was used with ultimate tensile stress, tangent modulus, ultimate strain, total growth plate thickness and reserve zone thickness as dependent variables, and with site and subject as factors. Paired Student t-tests were then used to determine if any of the dependent variables differed by site (capital femoral versus greater trochanter).

RESULTS

There were differences in the dependent variables between the capital femoral and greater trochanter sites (manova, $p = 0.02$). Not only was the overall growth plate thickness greater in the greater trochanteric than in the capital femoral growth plate (Tables 1 & 2), but the reserve zone occupied a proportionately larger fraction of the total growth plate. On the other hand, no differences were found in any of the tensile mechanical properties.

The mean (SD) thickness of these microstructural samples was 0.548 (0.051) mm, and width was 2.605 (0.280) mm. The mean (SD) strain rate of the tensile test was 0.005 (0.002) s^{-1}.

Mean ultimate stress varied linearly with mean tangent modulus (strength = 0.25 + 0.19 tangent modulus (MPa), $R^2 = 0.58$, $p = 0.006$ for the femoral head; and strength = 0.46 + 0.19 tangent modulus (MPa), $R^2 = 0.48$, $p = 0.0004$ for the greater trochanter).

DISCUSSION

In the present study, the ultimate stress, tangent modulus and ultimate strain of different growth plates in the same animal were not significantly different, despite a two-fold difference in total thickness and an almost four-fold difference in the ratio of reserve zone to total growth plate thickness. This contrasts with previous findings that the ultimate tensile strength of samples, taken from different regions of the bovine proximal tibial growth plate, varied inversely with growth plate thickness [2]. Since the plane of failure was observed to occur at the junction between the columnar and reserve zone, this suggests that ultimate tensile strength in the proximal femur may be more dependent on the collagen content of the intra-territorial and inter-territorial matrix than on growth plate thickness or reserve zone thickness.

In contrast to previous work on the proximal tibial growth plate [2], the present study found no correlation between any of the mechanical properties and growth cartilage or reserve zone thickness. In agreement with previous studies [1,2], there was a moderate correlation between ultimate stress and the tangent modulus, implying that both of these mechanical properties increase with some other factor, such as perhaps collagen content.

For comparison, human capital femoral epiphyseal samples, taken from 8 and 14 year old cerebral palsy patients, had a growth plate thickness of 1.35 (0.33) mm, reserve zone fractional thickness of 60-80%, ultimate stress of 0.98 (0.29) MPa, tangent modulus of 4.26 (1.22) MPa, and ultimate strain of 31 (7) % [2]. Thus the human capital femoral growth plate had about twice the growth plate thickness, three times the reserve zone fraction, half the ultimate stress and tangent modulus, but similar ultimate strain, as compared to 5-month old calves.

Table 1. Means (SD) of Growth Plate Dimensions

	Growth Plate Thickness (mm)	*Reserve Zone Thickness (mm)*	*Reserve Zone Fractional Thickness (%)*
Capital Femoral Growth Plate (N=10)	0.68 (0.15)	0.14 (0.08)	20 (11)
Greater Trochanteric Growth Plate (N=10)	1.28 (0.49)	1.00 (0.41)	76 (16)
Paired Student t-test	0.01	<0.0001	<0.0001

Table 2. Means (SD) of Growth Plate Mechanical Properties

	Ultimate Tensile Stress (MPa)	*Tangent Modulus (MPa)*	*Ultimate Tensile Strain (%)*
Capital Femoral Growth Plate (N=10)	2.16 (0.76)	9.98 (3.16)	32.5 (9.4)
Greater Trochanteric Growth Plate (N=10)	2.21 (0.73)	8.23 (2.04)	37.2 (9.6)
Paired Student t-test	0.88	0.12	0.40

CONCLUSIONS

This is the first study to directly compare microstructural tensile properties of different growth plates in the same bone. Despite large differences in growth plate and reserve zone thicknesses, we found that the two growth plates in the proximal femur had similar mechanical properties.

REFERENCES

1. Cohen, B., Chorney, G. S., Phillips, D. P., Dick, H. M., Buckwalter, J. A., Ratcliffe, A., and Mow, V. C., 1992, "The Microstructural Tensile Properties and Biochemical Composition of the Bovine Distal Femoral Growth Plate," Journal of Orthopaedic Research, Vol. 10, pp. 263-275.
2. Williams, J. L., Do, P. D., Eick, J. D., and Schmidt, T. L., "Tensile Properties of The Physis Vary With Anatomic Location, Thickness, Strain Rate and Age," Journal of Orthopaedic Research, Vol. 19: 1043-1048.