A HIERARCHICAL MODEL OF GROWTH PLATE CARTILAGE BASED ON SCANNING ELECTRON MICROSCOPY OF PHYSSEAL FRACTURE SURFACES AFTER TENSILE TESTING

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Relevance to the Musculoskeletal Condition: This study examined the three-dimensional aspects of the fracture surface through growth plates tested to failure in tension. This has relevance to fractures in children.

Introduction: There is great variability in the reported plane of fracture under tension loading. Some studies indicate that fracture occurs between the zones of maturation and hypertrophy, some show fractures through the upper zone of columnation and others find failure to occur through the resting zone. Several studies report that the individual columns of chondrocytes appeared to remain intact with separation occurring between columns. These previous reports were based on transmitted light microscopy of thin sections of embedded samples. We hypothesized that scanning electron microscopy would provide more complete information of the fracture characteristics than is possible to obtain from thin sections.

Methods: Tibiae were obtained from four heifers (12 to 18 months of age) raised without steroidal implants. Samples of bone-growth plate-bone were cut with the longest dimension along the tibial axis (0.56 mm x 2.66 mm x 15 mm) from a 25 mm band, centered in the antero-posterior direction. Samples were tested in tension at 0.0004 or 0.04 mm/sec to failure. Following testing to failure, ten samples (five tested at each testing speed) were processed for scanning electron microscopy. These were placed in 2.5% glutaraldehyde in 0.1 M sodium cacodylate buffer, pH 7.4, followed by dehydration in sequential ethanol baths of concentrations increasing from 33% to 100%, then kept in hexamethyldisilazane for 4 hours and dried. Fractured samples were glued to mounts, sputter coated with silver paint and viewed at x75, x300, x745 and x2500 magnification with a Phillips SEM 515 scanning microscope at 15 kV.

Results: Scanning electron microscopy confirmed the previous finding, based on two-dimensional thin sections of embedded samples, that individual columns of chondrocytes with their territorial matrix (chondrons) remained essentially intact. These chondrons sometimes were left still attached to others, forming clusters of five or more, while some were left isolated by partial or complete tears through the interterritorial matrix. The failure zone in our study occurred in the upper zone of columnation of the chondrons, sometimes deviating into the resting zone. A consistent finding was that most of the chondrons remained on the metaphysial side of the fracture (Figure 1), leaving a partially intact network, resembling a honeycomb, of interterritorial matrix on the epiphyseal side (Figure 2). Remnants of this network could be seen on the metaphysial side. We did not observe any differences in fracture pattern with speed of testing.

Discussion: SEM micrographs showed that chondrons pulled out of and away from the interterritorial matrix, leaving the originally overlapping and interdigitating interterritorial matrix and chondrons on opposite sides of the fracture surface. The path of least resistance in uniaxial tension appeared to be the interface between the territorial matrix of the chondron and the surrounding interterritorial matrix. By analogy, fractures through bone tend to propagate around the interface between osteons and interstitial bone. At the lowest level of organization cartilage may be viewed as a matrix of collagen and proteoglycans. We propose a microstructural model of growth plate cartilage, at another level of organization, one level up the hierarchical scale, in which the tubular chondrons pass from the primary spongioida into the resting zone and are weakly attached to a honeycomb-like structure of interterritorial matrix.

Small samples from relatively flat regions of the growth plate produced what we believe to be an approximation of a uniaxial state of tension. The three-dimensional aspects observed by scanning electron microscopy would be difficult to discern from thin sections. This may explain some of the disagreements in the literature as to the zone of failure. The location and pattern of failure may vary with the stage of development of the growth plate, due to differences in strength of the territorial and interterritorial matrices or in the degree of clustering or continuity of the chondrons.

Acknowledgments: We thank Deloris Sackruch and Scott J. Robinson for expert handling and preparation of the SEM specimens.

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The authors have not received anything of value from a commercial or other party related directly or indirectly to the subject of my presentation.