OSTEON TRAJECTORIES NEAR THE EQUINE METACARPUS NUTRIENT FORAMEN

Barbara Garita, M.S. & Andrew J. Rapoff, Ph.D.

University of Florida
Department of Mechanical and Aerospace Engineering
Department of Biomedical Engineering
Gainesville, Florida

ABSTRACT
We have discovered the presence of an organized group of transverse osteons on the apices of a natural hole in the equine third metacarpus (MC3). Considering the *in vivo* loading environment of the MC3, the osteons are located in a region of transverse tension. This arrangement may locally increase the toughness of the tissue.

INTRODUCTION
The purpose of this study is to describe osteon trajectories near a natural hole - the primary nutrient foramen - in the equine third metacarpus. Most long bones contain a primary nutrient foramen, a hole in the cortex through which arteries and veins transit. The equine MC3 foramen is located on the palmar aspect distal to the carpometacarpal joint, approximately one third of the way down the bone (**Figure 1**). The foramen is elliptical (2 to 4 mm diameter), with the major axis aligned longitudinally with the MC3. The foramen centerline is nominally perpendicular to the palmar surface.

We previously discovered near this foramen a microstructure that reduces the local stress concentration [1]. We have shown that this microstructure also increases structural strength [10]. We mimicked the elastic and strength manifestations of this microstructure in the design [7] and fabrication [1] of a plate with a central hole, and demonstrated the superior performance of this biomimetic design [1]. We recently have shown that this microstructure also increases damage resistance and tolerance ("toughness") in response to cyclic loading [4]. We postulate that osteon trajectories near the foramen (in some locations, radially within the cortex) exist in regions of transverse tension stress in response to global loading and that this arrangement locally increases toughness.

METHODS
Four equine third MC3s were obtained from an animal tissue service for this and a related study. The bones came from skeletally mature animals less than five years of age and without skeletal abnormalities. All procedures involving animal tissue use were conducted under the approval and auspices of our Institutional Animal Care and Use Committee. The bones were cleaned of soft tissue and stored at –26ºC until further preparation.

Rough cuts were made first with a diamond blade band saw to separate the palmar from the dorsal aspects. Three longitudinal sections, 2 mm thick in the endoperiosteal direction, were cut with a precision diamond blade band saw from the palmar aspect with the foramen centrally located. One parasagittal section (approximately 5 mm thick in the mediolateral direction) was cut from the palmar aspect with the foramen centrally located. Each section was mounted on a

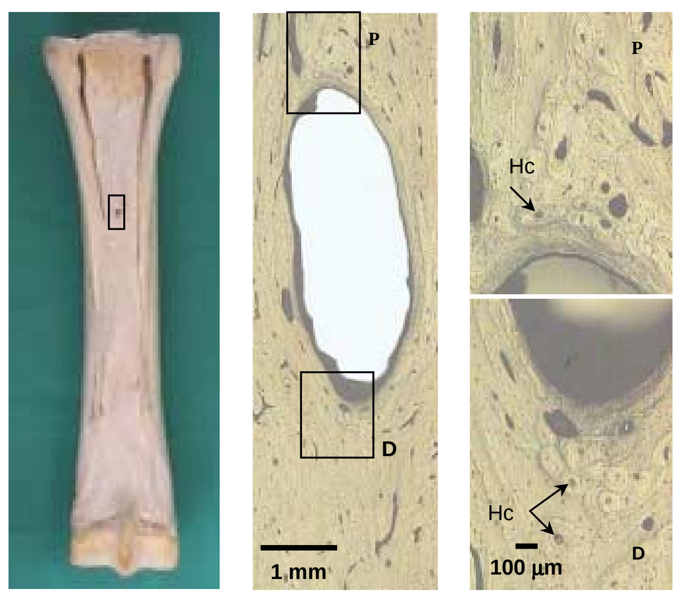

Figure 1. (Left) Palmar view of the MC3. (Center) Photomicrograph of the foramen. (Right) Proximal (P) and distal (D) apexes of the foramen; osteons are evident by the presence of Haversian canals (Hc).

petrographic glass slide, ground with 600 grit silicon carbide waterproof sand paper in combination with a 3 μm diamond slurry and polished manually until no scratches were visible under the microscope. Successive polishings were performed on the parasagittal section so as to observe osteon trajectories while approaching the foramen mediolaterally. The bones and sections were kept hydrated with purified water during all the processing and storage.

All sections were observed under a reflected light microscope. The most periosteal surface of each longitudinal section and the most lateral surface of the parasagittal section was observed under 40X magnification. Digital images of regions around each foramen were captured with a CCD camera, installed on the microscope and connected to a frame grabbing card. The images were cropped and merged to form mosaics of larger regions (**Figures 1 and 2**, center images).

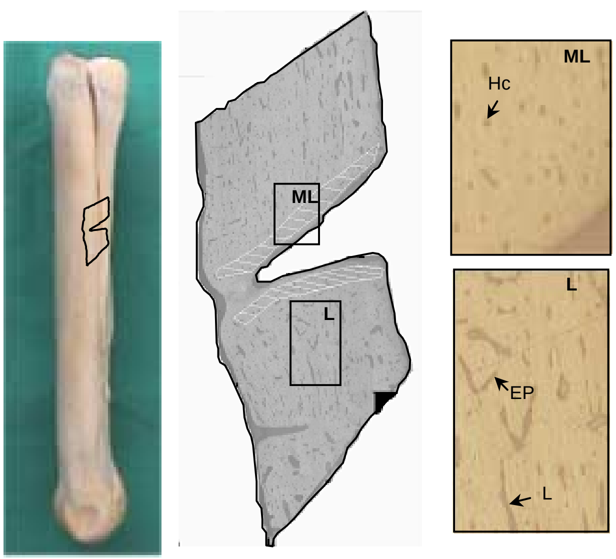

Figure 2. (Left) Lateral view of the MC3. (Center) Parasagittal section through the foramen. The lightly "striped" regions are where osteons with mediolateral (ML) trajectories were found. Longitudinal (L) osteons were found beyond the apexes of the foramen. (Right top) Magnified views of mediolateral osteons evident by the presence of Haversian canals (Hc). (Right bottom) Haversian canals traversing a common longitudinal direction (L) and others in an endoperiosteal (EP) direction.

RESULTS

Osteons with endoperiosteal trajectories were evident on the most periosteal surface, specifically on the distal and proximal apexes of the nutrient foramen (**Figure 1**). These osteons did not disrupt the lamellar layer lining the foramen evident in the images and reported previously by us [5]. These osteons were bundled together within a triangular shaped region, and were similar in size and elliptical in shape.

Observations on the parasagittal section yielded diverging osteon trajectories (**Figure 2**). Osteons become apparent in the mediolateral direction, outlining the foramen edges. Longitudinal osteons did not reach the edge of the hole, and some turned to become endoperiosteal osteons observed in the longitudinal sections. Many of the osteons were elliptical in shape.

DISCUSSION

The gross shape and heterogeneous mechanical properties of the MC3 reflect its function in response to evolutionary adaptation for efficient and safe high speed ambulation [8]. Its length and large cortical cross sectional area give it an inherent resistance to both buckling and static compression failure: safety factors (SFs) exceed 5 on buckling and approach 2 on compressive strength for horses in a trot [1,3], but only slightly exceed 1 on fatigue strength [3]. The low fatigue SF reflects the high incidence of stress fractures in racing horses, up to 70% in young thoroughbreds [9]. These fractures occur on the dorsal aspect of the MC3, an area of predominant tension [6], diametrically opposite the location of the foramen. Thus, the foramen exists in a region of predominate longitudinal compression.

It is well known that a transverse tension stress field exists in the "upstream" and "downstream" regions near an elliptical hole in a plate subjected to far field longitudinal compression. Such regions exist near the proximodistal apexes of the MC3 foramen. It is in these regions that we observed endoperiosteal osteon trajectories, especially evident nearest the periosteal surface of the MC3. The periosteal surface represents the surface of greatest compressive bending normal stress, and, thus, the greatest transverse tension in the foramen apexes. Osteons perpendicular to this tension present their cement lines as possible crack arrestors and, along with diverging osteons which may deflect cracks, may increase toughness in these regions.

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