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BONE SURFACE/VOLUME RELATIONSHIPS IN SIMULATED VS. ACTUAL OSTEONS: THE CONFOUNDING INFLUENCES OF ULTRASTRUCTURAL COMPLEXITY

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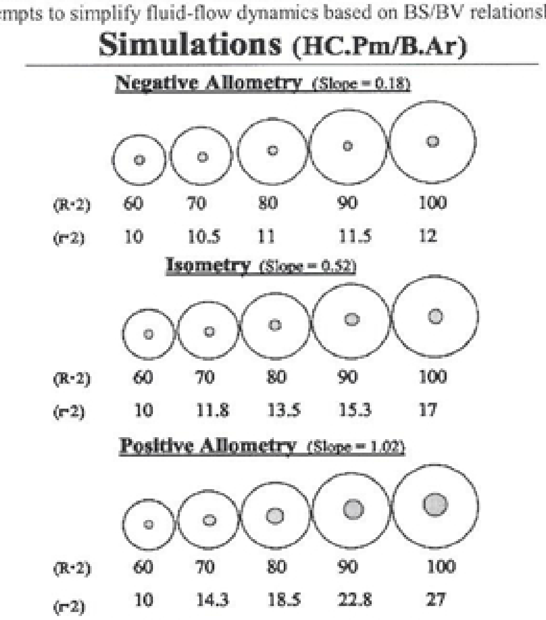
INTRODUCTION: Dynamics of remodeling and convective fluid flow/nutrient delivery in 2[nd] osteons of human ribs are often broadly extrapolated to appendicular bones. However, when compared to appendicular bones, ribs are metabolically more active. In addition to a growing interest in computational modeling of these osteon dynamics, the importance of osteons in "toughening" limb bones is revealed by data showing that they can form 'morphotypes' that differentially influence energy absorption [1]. In limb bones, these osteon morphotypes are: **1)** distinguishable by different collagen organization (e.g., parallel-fibered osteons in 'tension' and alternating osteons in 'compression' environments), and **2)** are associated with bone "quality" [1,2]. We explored putative metabolic/mechanical functions of osteons by testing the hypothesis that bone surface (BS) area (Haversian canal) to bone volume (BV, osteonal bone area) relationships in rib osteons differ from those in osteons of limb bones. We also investigated these relationships in non-rib bones in habitual 'tension' and 'compression' regions (where morphotypes differ), and in 'neutral axis' regions (where strain gradients correlate with greatest fluid flux).

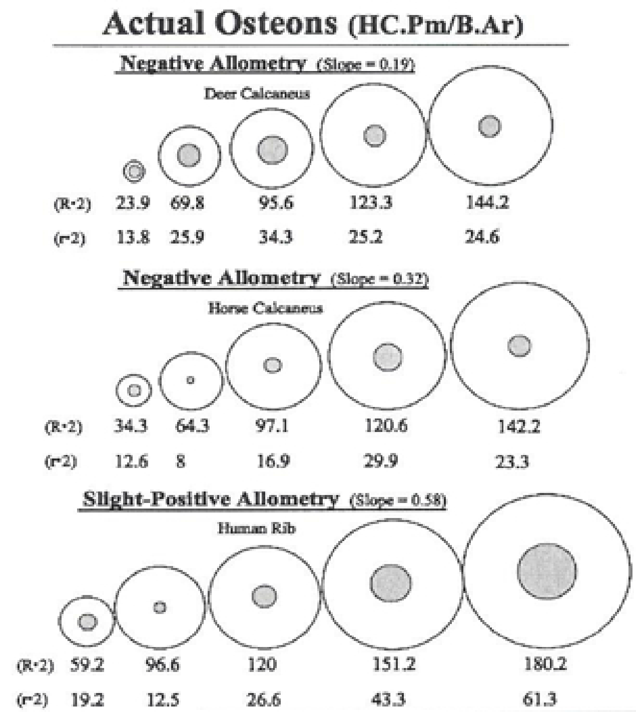
METHODS: 50X backscattered electron images were obtained from cranial 'tension', caudal 'compression', and medial (M), and lateral (L) cortices of mid-third diaphyses of 10 mature (ages 2-10) horse radii and third metacarpals, and the dorsal 'compression', plantar 'tension', and M/L ('neutral axis') cortices of sheep, deer, elk, and horse calcanei. Over 5,000 fully formed osteons were examined for osteonal area (On.Ar), osteonal bone area (B.Ar), and central (Haversian) canal perimeter (Hc.Pm); the 2D parameters Hc.Pm and B.Ar are considered BS and BV. Human rib data were from [3]. Scaling relationships of BS/BV were examined using log-transformed data (to make an exponential function linear) and least-squares regression analyses [4], where proportionality in BS/BV scales with a slope of 0.5 ("isometry"), and <0.5 represents negative and >0.5 positive allometry. Five actual and simulated osteons were also selected or created to illustrate these possibilities; these osteons were from quartiles between min-max On.Ar.

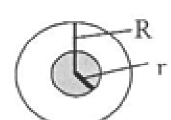
RESULTS AND DISCUSSION: Results summarized below for all osteons and in the figure at the right showed ~isometry or slight positive allometry in the ribs. This contrasts with negative allometry shown consistently in the non-rib osteons regardless of location. Although the typically proportionally larger canals in ribs might reflect up-regulated metabolic activities, simplified modeling of the convective fluid flow or nutrient/calcium exchange across the canal surface (HC.Pm) to/from the target volume (B.Ar) could belie the detection of additional complexities. These include the possibility that osteons can also exhibit differences in lacuno-canalicular geometries that represent the conduits for trans-osteon fluid flow [5]. Recent data suggest that such differences correlate with differential mechanotransduction [6]. Consequently, studies of osteon fluid-flow dynamics and related remodeling dynamics must no longer perceive osteons as entities with generalized/uniform ultrastructural organization. Comparisons between rib and appendicular osteons cannot be made without considering these additional issues. Biomechanically significant differences in osteon populations and/or their morphotypes between bones or bone regions may correlate with lacuno-canalicular geometry differences, potentially reflecting site-specific differences in mechanotransduction. This further complicates attempts to simplify fluid-flow dynamics based on BS/BV relationships.

BS/BV RELATIONSHIPS (HC.Pm vs. B.Ar; Isometry = 0.5)

Species	Cortex	LS Slope	r	p
Sheep Calcaneus	Dorsal	0.12	0.22	0.21
	Plantar	-0.004	0.01	0.93
	Medial+Lateral	-0.003	0.01	0.96
	All locations	0.01	0.03	0.69
Deer Calcaneus	Dorsal	0.08	0.15	<0.01
	Plantar	0.16	0.28	<0.01
	Medial+Lateral	-	-	-
	All locations	0.12	0.21	<0.01
Elk Calcaneus	Dorsal	0.11	0.2	0.03
	Plantar	0.17	0.26	0.03
	Medial+Lateral	0.17	0.34	<0.01
	All locations	0.15	0.24	<0.01
Horse Calcaneus	Dorsal	0.17	0.28	<0.01
	Plantar	0.28	0.43	<0.01
	Medial+Lateral	0.20	0.44	<0.01
	All locations	0.21	0.39	<0.01
Horse Radius	Cranial	0.19	0.38	<0.01
	Caudal	0.23	0.39	<0.01
	Medial+Lateral	0.002	0.004	0.9
	All locations	0.21	0.41	<0.01
Horse MC3	Dorsal	0.1	0.2	<0.01
	Palmar	0.1	0.23	<0.01
	Medial+Lateral	0.09	0.22	<0.01
	All locations	0.09	0.21	<0.01
Human Rib	All locations	0.45	0.61	<0.01







Measurements are in microns

REFERENCES: **1)** Hiller et al. 2003 J Orthop Res 21:481; **2)** Skedros et al. 2006 Trans ORS 1600; **3)** Qiu et al. 2003 Anat Rec 272A:520; **4)** Schmidt-Nielsen, K. 1984 Scaling: Why is animal size so important? N.Y.: Cambdg. U. Press. **5)** Mishra & Knothe-Tate 2003 Anat Rec 273A:752; **6)** Wang et al. 2006 Trans ORS 192.

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