Resolving Stressful Relationships in Prehistory:
Macroscopic and Histological Indicators of Growth Disruption in Subadult Long Bones

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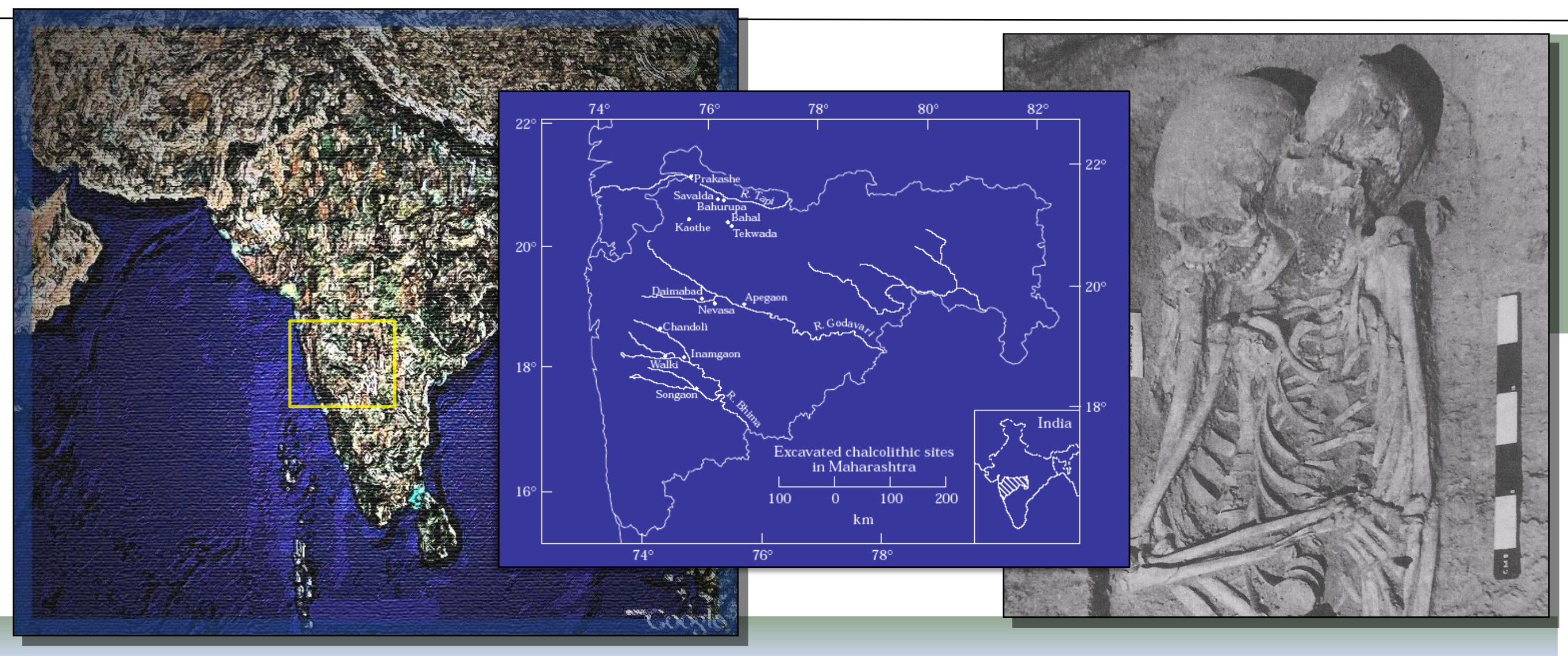
In the past two decades, research on growth in cortical bone cross-sectional parameters has suggested:

1) Percent Cortical Area (total area - medullar area = %CA), once used to determine nutritional status from long bone cross-sections, declines as part of a 'normal' pattern of growth during infancy.
2) In circumstances of adequate nutritional status, declines in %CA are accompanied increases in mass at the periosteal surface, which provide greater relative strength to the bone despite the thinner cortex.
3) Strength in the humerus increases at a faster velocity relative to the femur during the 6-12 month age category (when infants are generally beginning to acquire locomotor skills related to crawling). The growth velocity of femoral strength is relatively faster after 12 months of age (with bipedal locomotion).
4) Thus the general decline in %CA that people had previously interpreted as nutritional stress (e.g. Garn, 1970; Keith, 1984) was now explained as a function of normal growth.



Macroscopic Perspectives on Biocultural Stress in Compact Bone Growth and Development

Recent research on compact bone properties for 76 humeri and femora of infants and children (0-5 years) from the Deccan Chalcolithic (DC) period in India has demonstrated a different pattern of growth that suggests growth suppression at the periosteal surface (Robbins, 2007a, b).

Hypothesis: Growth suppression at the periosteal surface of the femur in the Deccan Chalcolithic samples is due to high biocultural stress levels and a synergistic relationship between poor nutritional status, low body mass, and lack of activity.

Prediction: If velocity of compact bone growth is reduced due to high biocultural stress levels, then affected individuals will also demonstrate low body mass for height and histological indicators of growth disruption.

Fig. 1: Humerus and Femur Zp in the Denver (top) and DC (bottom) samples

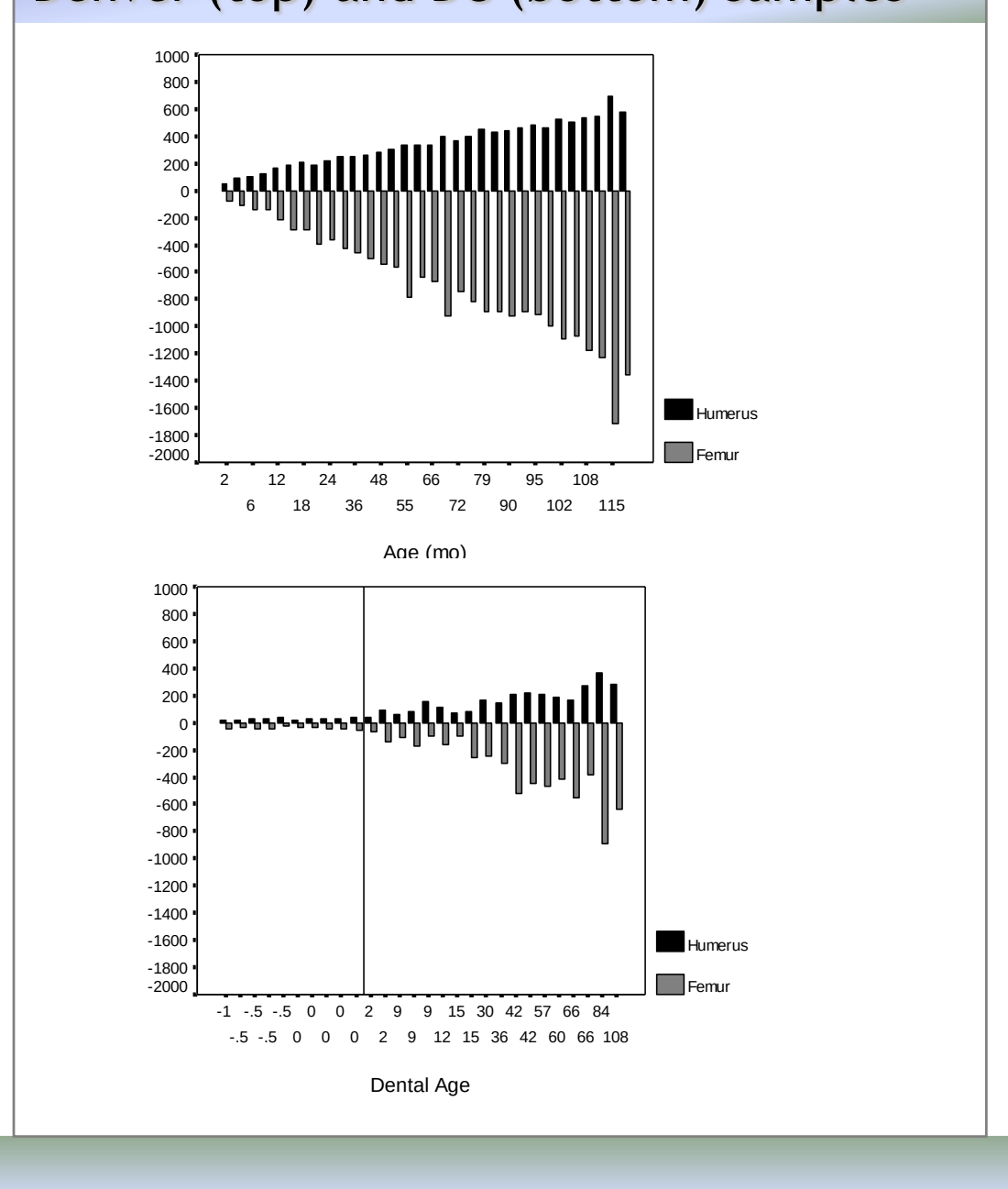


Fig. 2: Diameter of long bones in the Denver (top) and DC (bottom) samples

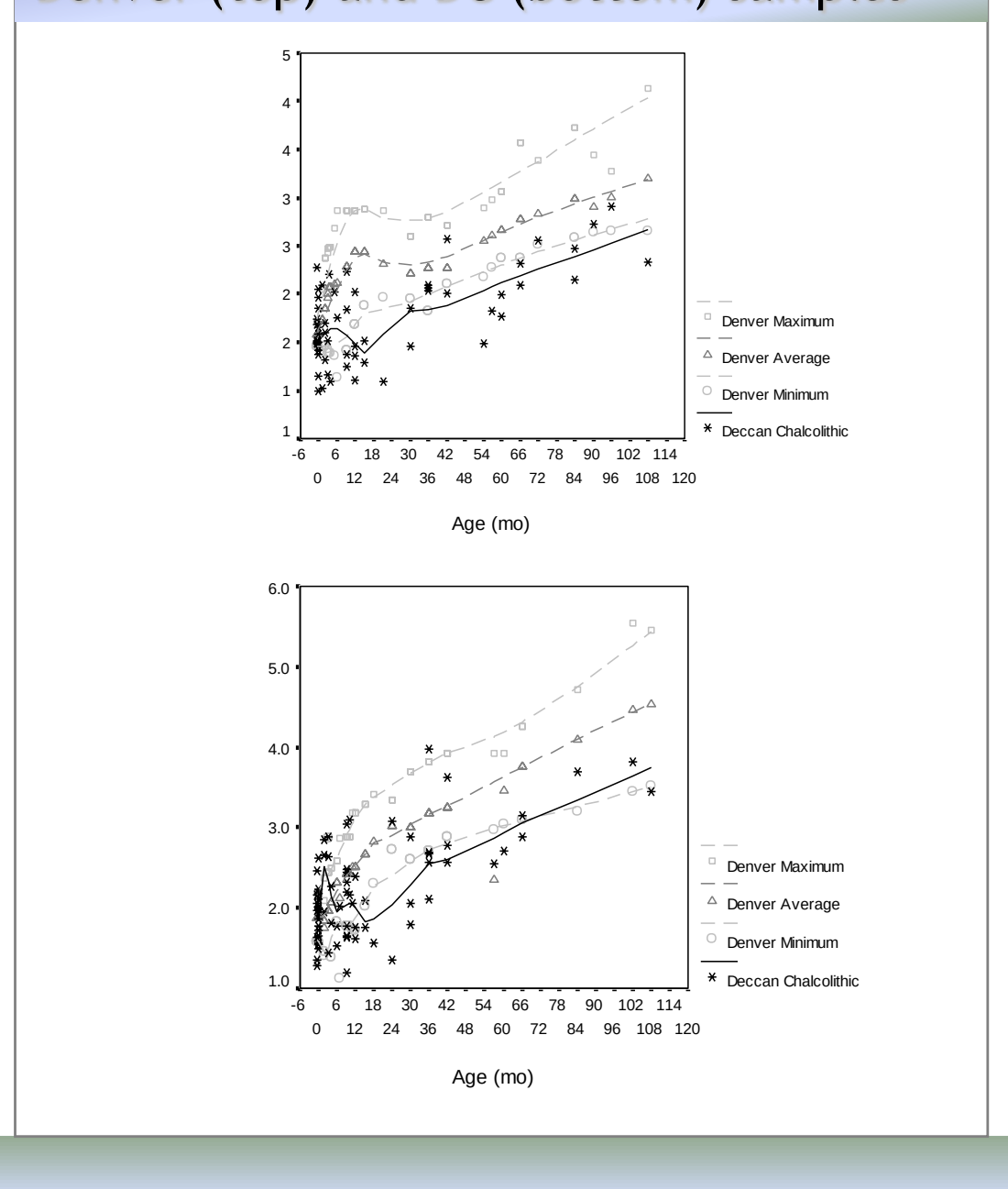
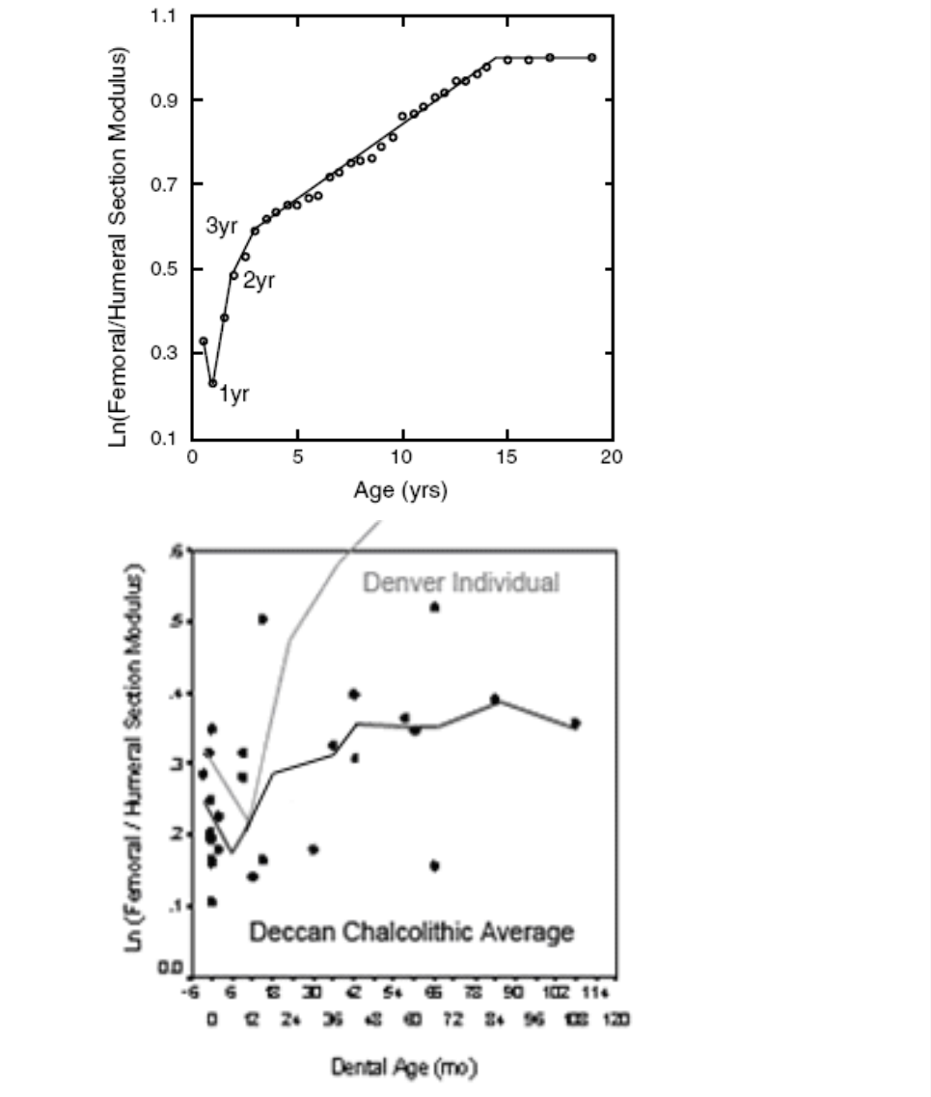


Fig. 3: Relative velocity of Zp in the humerus and femur for the Denver (top) and DC (bottom) samples



Predicting Body Mass from Femoral Cross-Section Properties

To use bone cross-section parameters as a biocultural stress marker, it is necessary to have an independent estimate of body mass. With archaeological samples, long bone ends may not always be preserved and previous methods of estimating body mass from the widths of those ends may not be feasible. Furthermore, the morphology of the ends could be affected if the infants and children are suffering from vitamin D deficiency. Approaching the question in reverse, if we use J (torsional strength) as an independent estimator of body mass (instead of a direct measure of stress) then we can look at body mass for height (Ruff 2007) to examine growth suppression.

Fig. 4: LS Regression has previously been used to estimate body mass in human infants based on metaphyseal ends of long bones (Ruff 2007)

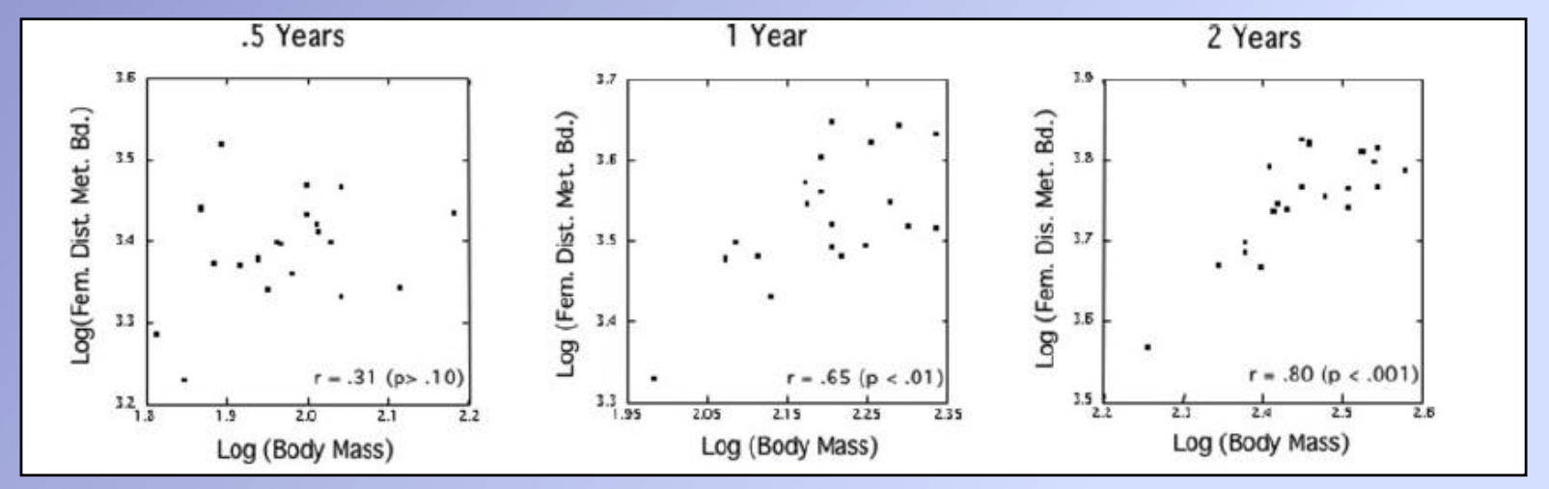


Fig. 5: Body mass also has a relationship to bone strength

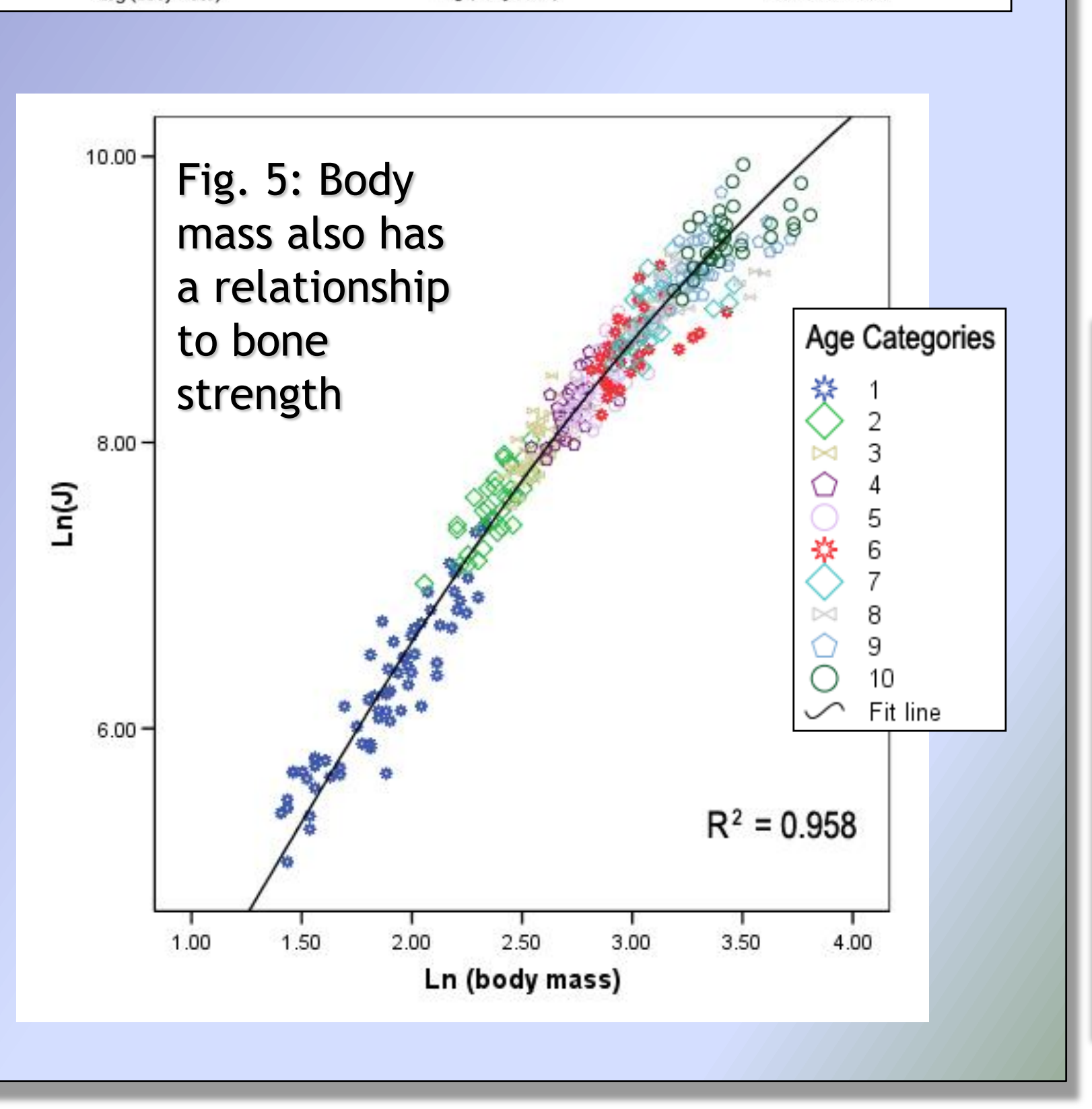
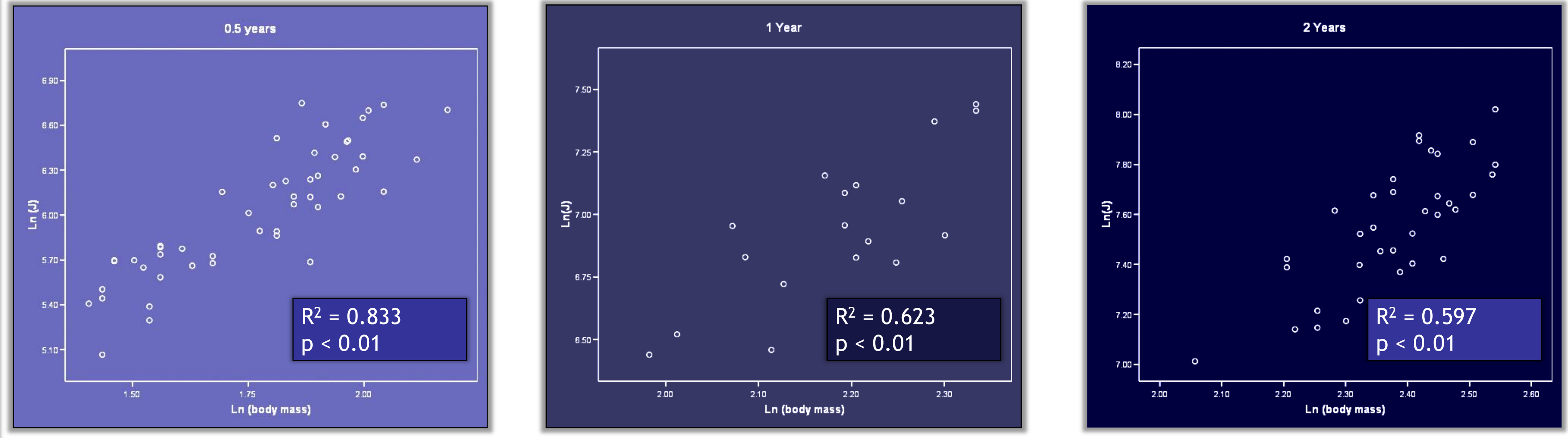


Table 1: prior probability of body mass given Ln (J) in the Denver sample (individuals age 1-10 years)

Ln body mass	N	Ln J									
		5.0-5.4 n = 5	5.5-5.9 n = 17	6.0-6.4 n = 18	6.5-6.9 n = 17	7.0-7.4 n = 21	7.5-7.9 n = 46	8.0-8.4 n = 77	8.5-8.9 n = 93	9.0-9.4 n = 87	9.5-9.9 n = 19
1.0-1.4	4	0.60	0.06								
1.5-1.9	33	0.40	0.94	0.67	0.18						
2.0-2.4	59			0.33	0.82	0.95	0.41				
2.5-2.9	137					0.05	0.59	0.99	0.36		
3.0-3.4	144							0.01	0.65	0.85	0.47
3.5-3.9	23									0.15	0.53

Fig. 6: LS Regression predicts body mass from Ln (J) in the Denver sample (individuals age 0.5-2 years)



Evaluating Growth Suppression Using Body Mass (kg) for Height (cm)

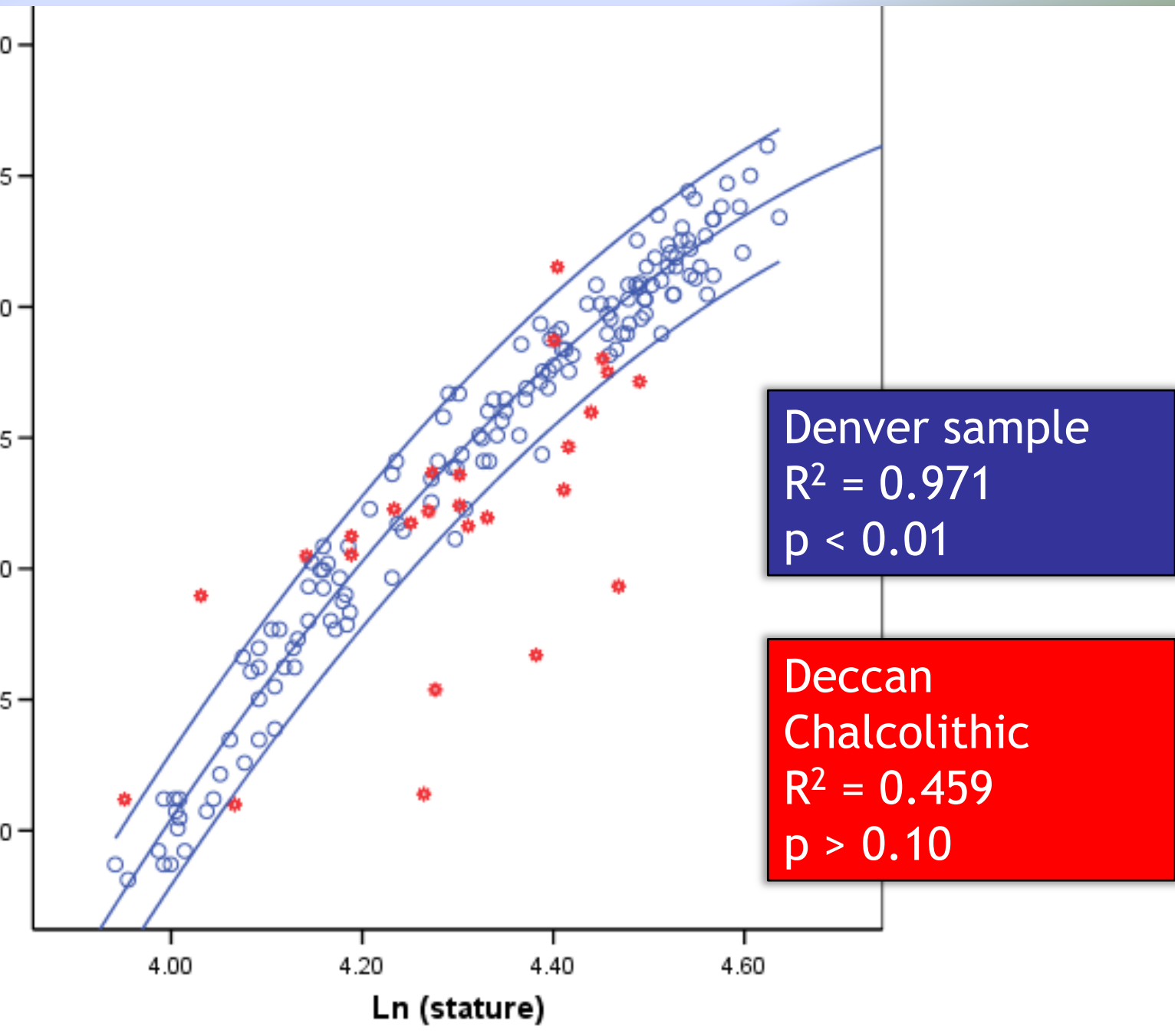
LS regression(Table 2) developed from the Denver sample were used to estimate body mass in DC children 2-36 months (n = 39) based on the torsional strength of the femur (Ln (J)). Then LS regression formulae were used to estimate stature from femoral length (Ruff 2007). The relationship between body mass and height in the DC sample was used as a proxy for poor nutritional status and reduced activity levels

Table 2: Equations for predicting body mass (kg) from Ln (J) for individuals 0-5 years (based on Denver sample data)

Age (yrs)	R^2	B_0	B_x	SEE	p
0.5	0.833	-0.871	0.439	0.104	0.000
1	0.623	0.296	0.272	0.650	0.000
2	0.597	-0.186	0.339	0.071	0.000
3	0.968	-0.798	0.423	0.084	0.000
4	0.652	0.372	0.286	0.071	0.000
5	0.454	0.330	0.298	0.071	0.000

Fig. 7: 11/39 (28.2 %) of 2-36 month old individuals from DC have bone cross-section properties consistent with low body mass for height (indices > -2 standard deviations from the Denver sample median). Stature calculated using femoral length (Ruff 2007).

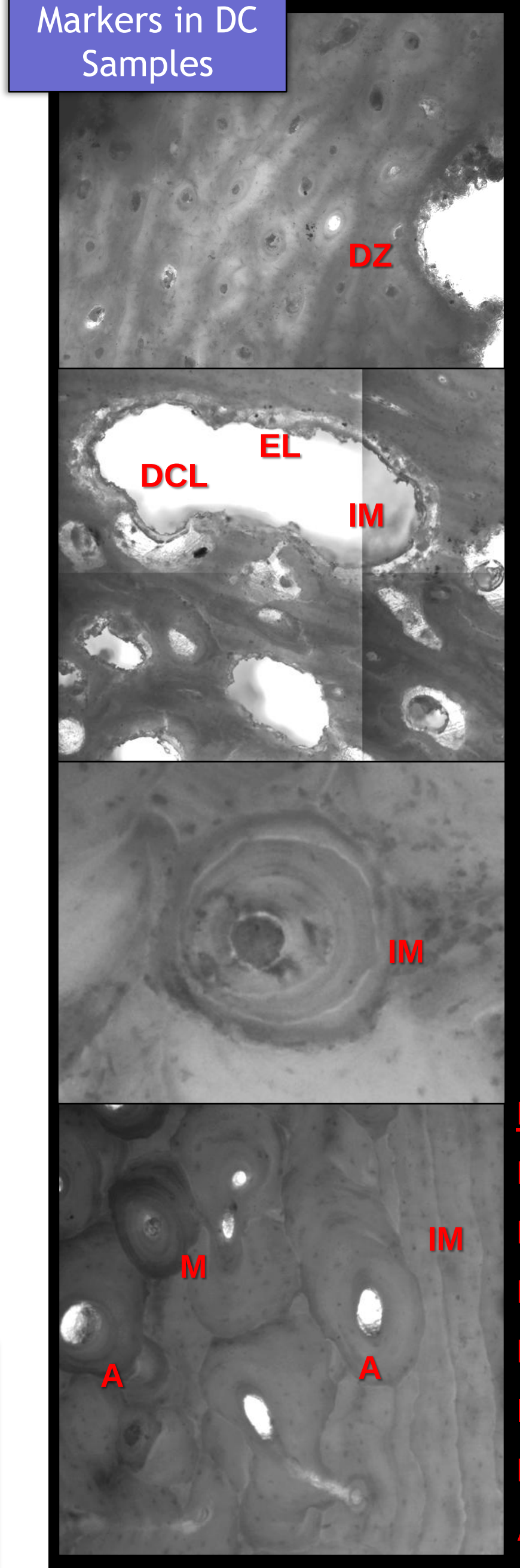
Fig. 7: Ln body mass (kg) versus Ln stature for individuals 2-36 months

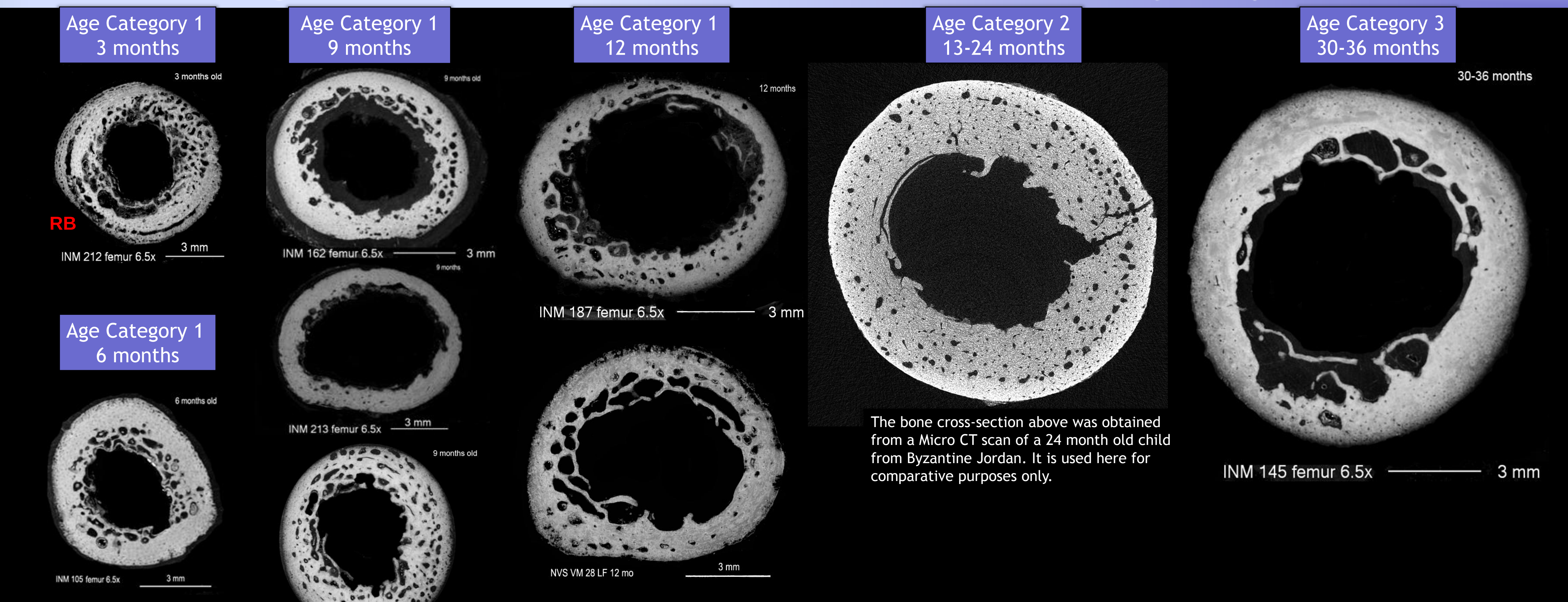


Histological Analysis of Individuals with Low Body Mass for Height

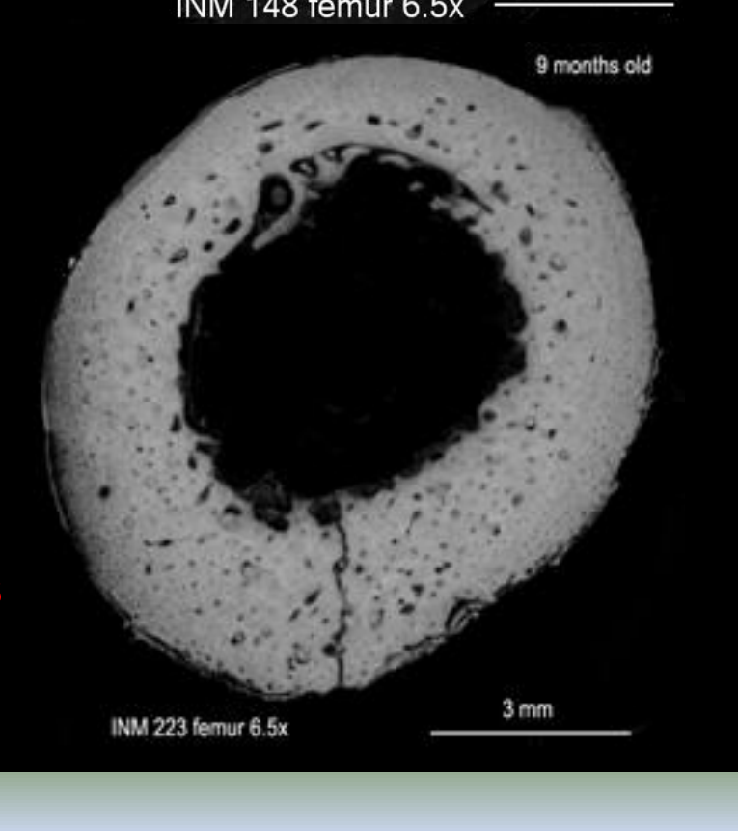
Microstructural indicators of growth disruption were observed in 100% individuals with low body mass predictions

Histological Markers in DC Samples





The bone cross-section above was obtained from a Micro CT scan of a 24 month old child from Byzantine Jordan. It is used here for comparative purposes only.



INM 223 (left) provided for comparison only. This individual did not demonstrate growth suppression in bone mass and histological markers were not present.

Legend
DZ: Double zone osteons
RB: Rapid bone formation
EL: Enlarged lacunae
DCL Defective cement lines
IM: Imperfect mineralization
M: Mature traveling osteons
A: Active traveling osteons

Table 3: Percent Individuals Affected by Biocultural Stress Markers in DC Sample

Biocultural Stress Markers	Dental Age (in months)						
	Perinate n = 46	1-6 n = 51	7-12 n = 52	13-24 n = 22	25-36 n = 21	37-48 n = 14	49-60 n = 6
Periostosis	0.28	0.20	0.15	0.18	0.10	0.07	0.17
Cribra orbitalia	.	0.02	0.02	.	.	.	.
Cranial Stenosis	.	.	.	.	.	0.07	.
LHPC and LEH		0.02	0.12	0.18	0.52	0.36	0.50
Greenstick fracture	0.02	0.06	0.06	.	.	.	.
Harris Lines		0.02		0.09	0.05		

Conclusions:

1) Bone cross section properties (J) predict body mass for young infants with relatively high accuracy and precision. Body mass estimates from compact bone midshaft dimensions or long bone ends (Ruff 2007) can be evaluated against stature to examine growth disruption and biocultural stress levels.
2) In the DC sample, body mass for height was significantly reduced in 28% of individuals. All of these individuals (n = 11) demonstrated increased porosity and enlarged lacunae in compact bone cross-sections as well as other microstructural indicators of growth disruption.

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