Intentional Cranial Vault Modification and the Biomechanics of Head Balance

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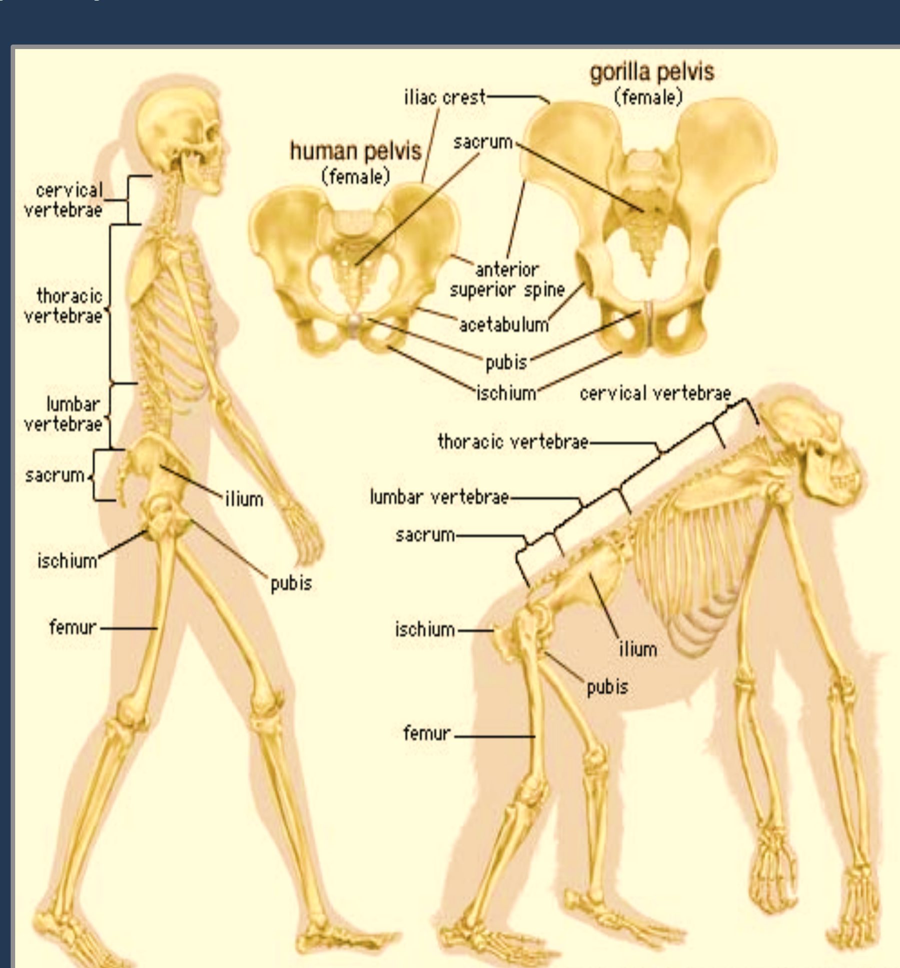
Introduction

Intentional cranial vault modification is a cultural practice that alters the shape of the skull, and thus how the skull balances[1]. At pre-Columbian sites in the Andean region, vault modification comes in **two main forms: circumferential (C),** achieved by wrapping cloth around an infant's head, **and anteroposterior (AP),** achieved by attaching stiff boards to the front and back of an infants head with cords or laces (Fig. 1).

Fig. 1 ***Cranial Vault Modification Types***
Right: Circumferential (C), AMNH 99/3197
Left: Anteroposterior (AP), AMNH 99/3679
Courtesy of the Division of Anthropology, American Museum of Natural History

Over the course of human evolution, the need to walk bipedally has influenced the shape of the skeleton, including the skull (Fig. 2). Because it must balance atop a vertically oriented vertebral column, human skull dimensions have been modified to minimize forces placed on neck musculature. This involves the migration of the foramen magnum to the center of the base of the skull, increased flexion of the cranial base, and a shortening of the face from front to back bringing the articulation of the head and neck at the atlanto-occipital joint (AOJ) closer to the head's center of gravity[2]. If one imagines the skull as a Class I mechanical lever with a fulcrum located at the occipital condyles on either side of the foramen magnum, with the load being the portion of the skull anterior to the condyles and the force consisting of the weight of skull posterior to the condyles and the power applied by the nuchal musculature, the centralization of this fulcrum reduces the amount of force required to keep the face upright (Fig. 5). While past studies on head balance have demonstrated that the human head balances better than those of non-human primates[3], **this study is unique in that it is the first to assess head balance in intentionally modified crania**.

Fig. 2 Human skeletal adaptations for bipedalism compared to quadruped apes



Research Questions and Hypotheses

- **Q1:** ***Does the cultural practice of cranial vault modification alter how the human skull balances on the vertebral column?***
- **H1:** This practice does indeed alter how the human skull balances on the vertebral column.

- **Q2:** ***Does the face, which completes development after the vault, develop in a way that can compensate for disequilibrium caused by vault modification practices?***
- **H2:** The growth of the face will reflect a compensation for crania disequilibrium induced by vault modification.

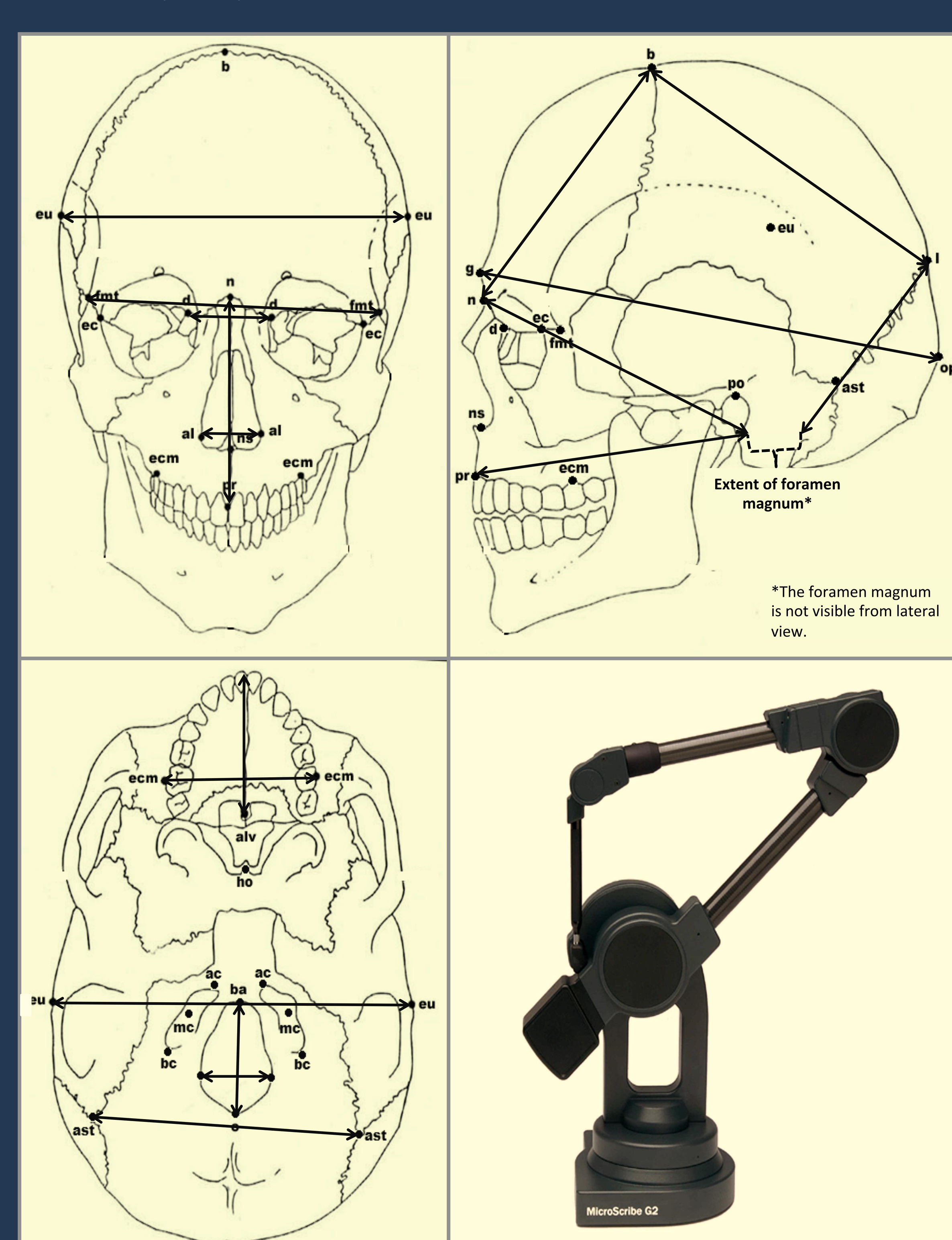
Materials and Methods

My sample consists of 96 adult crania from various sites in Peru and Bolivia (Fig. 3). The crania were divided into categories according to modification type: AP (n=20), C (n=39), or N (n=37).

Fig. 3 ***Locality map of major sites represented in sample***
Orange = Anteroposterior (AP), Red = Circumferential (C), Green = Unmodified (N)

A total of 41 craniometric points associated with standard craniometric measurements were digitized from each cranium using a MicroScribe 2Dx digitizer (Fig. 4). The 3D coordinates for these points were then used to extract 21 measurements of the base, face, and vault of each cranium by calculating the Euclidean distance between the appropriate points for all measurements. Angular measurements were taken in ImageJ using screenshots of wireframes made form the 3D coordinates in Morphologika v2.5. Head balance was assessed using Adams and Moore's (1975) definition of Cranial Position Index (CPI) (Fig. 5).

Fig. 4 MicroScribe Points and Linear Measurements
Counterclockwise starting at top right: Lateral View of Skull, Anterior View of Skull, Inferior View of Cranium, MicroScribe digitizer
Craniometric Points and Measurements are defined in Buikstra and Ubelaker (1994)



Results and Discussion

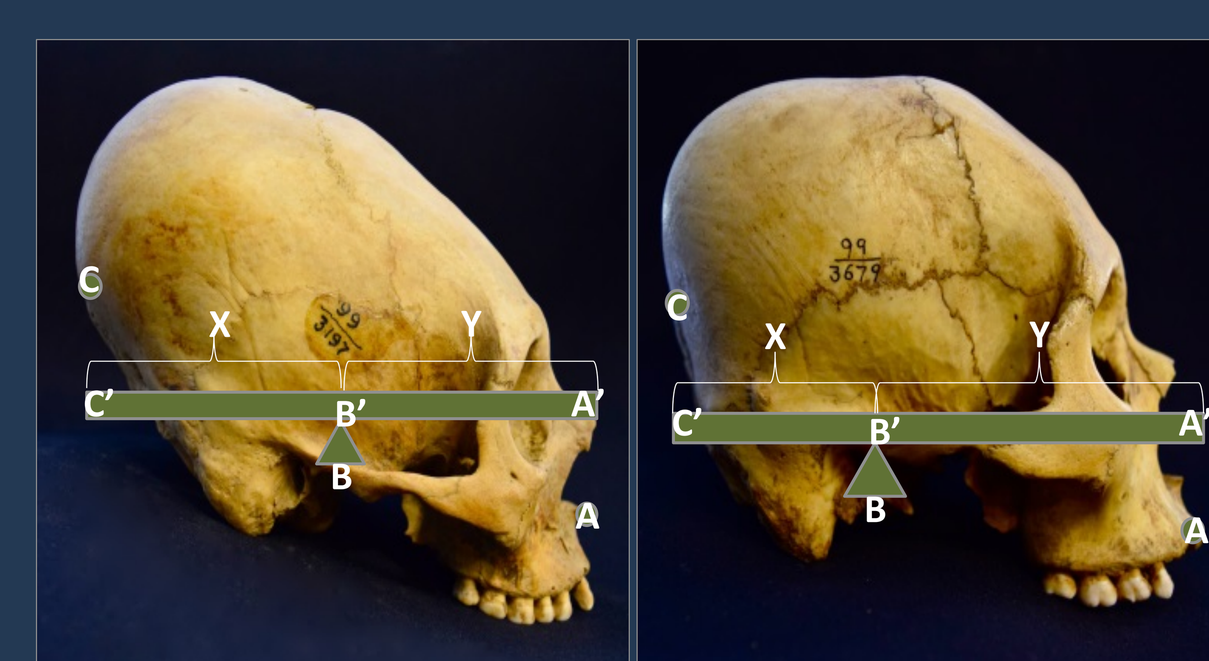
Hypothesis #1 - SUPPORTED

- Condylar Position Index differed significantly between all groups with both modified groups having lower average indices than the modified sample. **These results indicate that skull balance is compromised in both AP and C groups, but moreso in the AP.**
- Indices for all groups fell below 100. Thus, **none of the groups exhibited perfect head balance equilibrium.**

Hypothesis #2 - SUPPORTED.

- Neither the AP group nor the C group had a significantly different Face Angle (Nasion-Basion-Prosthion) This graded from the C group, with the smallest average angle measurement, to the AP group, with the largest. This reflects increased prognathism in the C group and increased orthognathism in the AP group. **The increased prognathism in the C group can be attributed in part to the C group having a significantly greater Palatal Length than either the AP or N groups. This may possibly counterbalance induced changes to the cranium that are detrimental to head balance.**
- **Differences in condylar angle between groups were not found to be statistically significant, suggesting that neither modification practice significantly altered the angle at which the spinal column articulated with the occipital condyles. This demonstrates a conservation of a more perpendicular articulation of the head and neck found in humans that is unique among primates.**

Fig. 5 ***Assessing the Cranium as a Class I Lever***
Top: Circumferential (C), AMNH 99/3197
Bottom: Anteroposterior (AP), AMNH 99/3679
Courtesy of the Division of Anthropology, American Museum of Natural History
A = Prosthion, B = Intercondylar Point, C = Opisthocranion
A', B', C' = projections of A,B, and C (respectively) on the Frankfurt Horizontal Plane;
X = distance between B' and C', Y = distance between B' and A'
CPI = (X/Y) x 100



Main Findings

- **Intentional cranial vault modification in both of its two main forms has a significant impact how the head balances. Of these, AP modification had the greatest impact on head balance.**
- **If one were to factor in the additional mass of the mandible anterior of the occipital condyles, the disequilibrium in the skull would be even greater.**
- **Growth of the face following the development of the vault compensates for the loss of cranial equilibrium generated by induced changes to the vault.**
- **Whether or not the influence of cranial vault modification on head balance was enough to create notable levels of strain on the neck musculature is uncertain, but decrease in head balance efficiency underscores the importance of this cultural practice as a cultural identifier as it was widely adapted despite its detrimental effect on the biomechanics of head balance.**

Literature Cited

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