Population-level assessment of cranial modification and atlanto-occipital fusion across Peru

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Introduction

Artificial cranial modification (ACM) has been practiced worldwide but occurs with the highest frequency in the Americas.[1] ACM was accomplished through compression devices like splints, wraps, or hats that exerted pressure on infants' malleable cranial bones, resulting in a variety of head shapes.[2] In pre-Hispanic Peru, ACM could be related to ethnicity, geographic origin, or status.[4] The desire to inscribe these layers of social meaning into physical appearance motivates ACM.[2,3]

Atlanto-occipital fusion (AOF) is a skeletal abnormality that is also distributed worldwide. AOF involves the partial or complete fusion of the first cervical vertebra (atlas) to the occipital bone, and it often co-occurs with spina bifida and fused transverse processes.[5] AOF is commonly described as a heritable, congenital condition, but environmental factors like disease or restriction of movement associated with ACM may also contribute.[6,7,8]

AOF has been previously described in populations from three regions of Peru and in one cranially-modified individual from Mexico.[6,9,10] Because several individuals with both AOF and ACM were observed in the Peruvian collections at the Smithsonian's National Museum of Natural History (NMNH), this study seeks to assess the relationship between ACM and AOF across Peru.

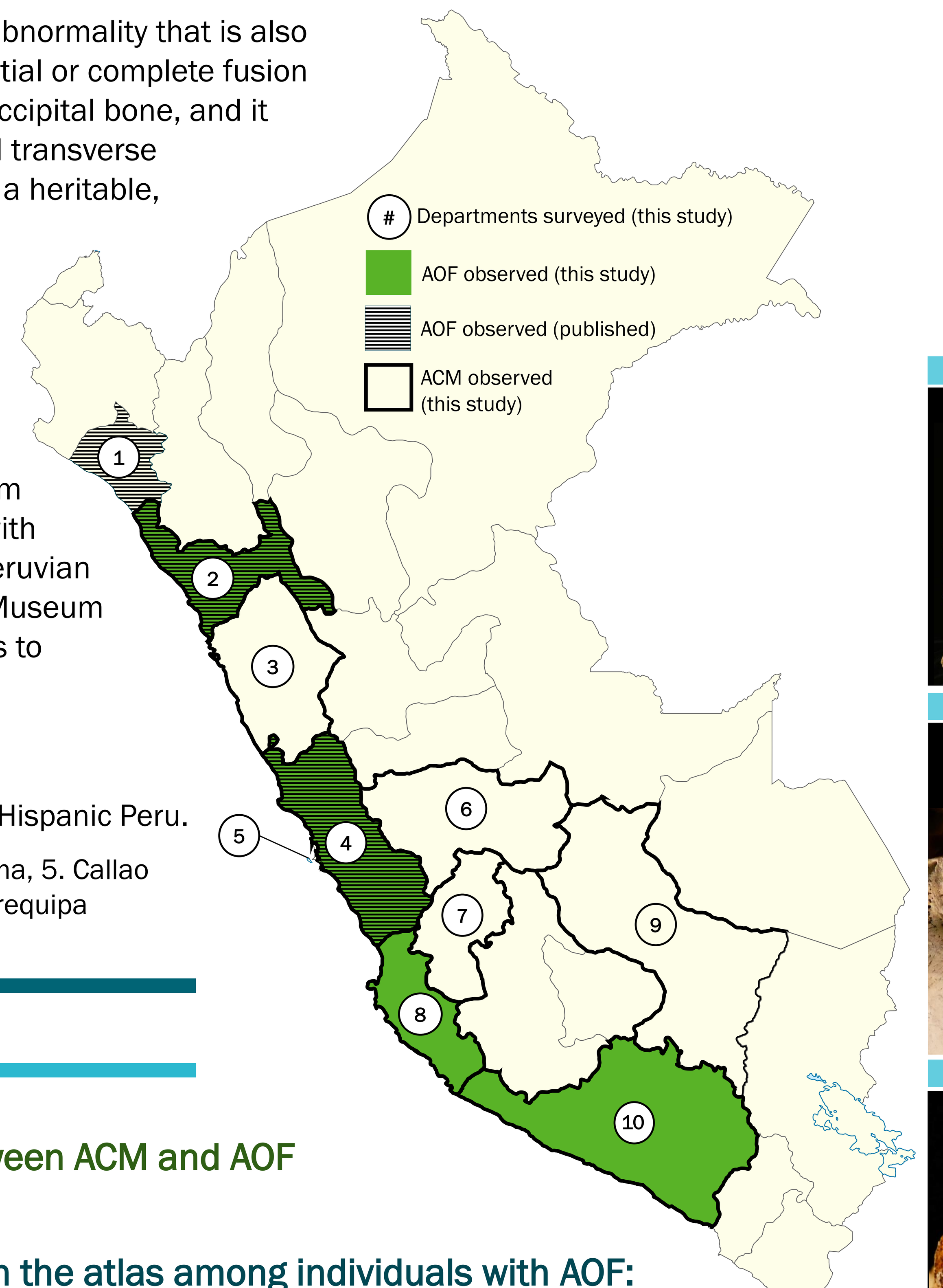


Figure 1 (right). Map of AOF presence in pre-Hispanic Peru.

1. Lambayeque, 2. La Libertad, 3. Áncash, 4. Lima, 5. Callao 6. Junín, 7. Huancavelica, 8. Ica, 9. Cuzco, 10. Arequipa

Objectives

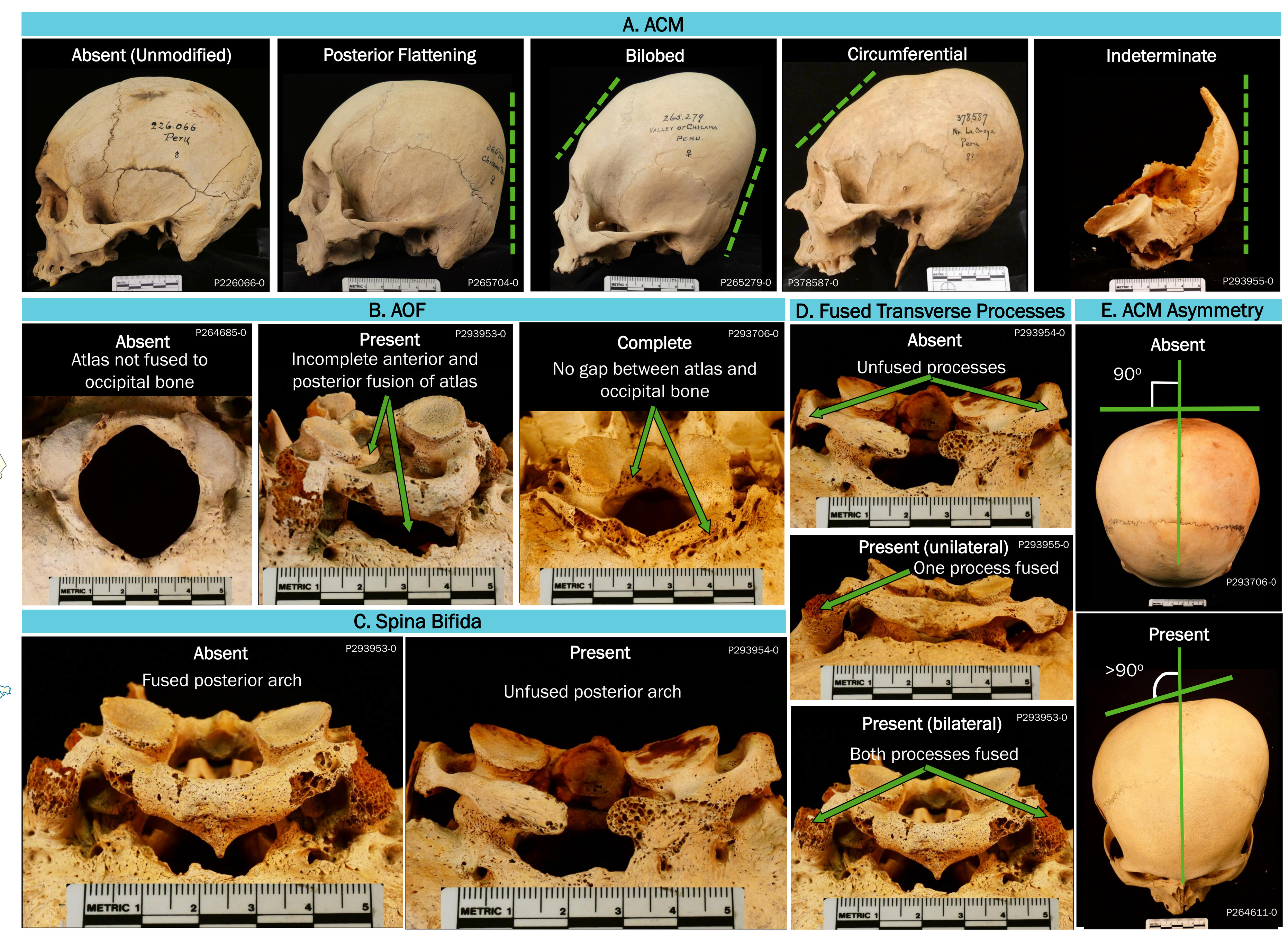
- investigate the relationship between ACM and AOF presence/completeness
- assess anatomical differences in the atlas among individuals with AOF: spina bifida, and fusion of transverse processes.
- compare the incidence of AOF in different regions of Peru.

Methods

In this study, 1407 crania from the NMNH's Peruvian collections were surveyed. They are dated to 1300-1500 CE and come from nine departments (states) in Peru (**Fig. 1**). Data was collected alongside the EMPHASIS survey, which assesses how environmental changes impact the skeleton.[11]

ACM was recorded as absent/present. If present, ACM type was assessed using overall shape of the cranial profile and zones of flattening (**Fig. 2, panel A**). Complete crania exhibiting ACM were categorized into three types, and fragments exhibiting ACM were classed as indeterminate (**Fig. 2, panel A**).[3] AOF was recorded as absent or present. If present, completeness of fusion was classified as partial or complete (**Fig. 2, panel B**). Complete fusion of the atlas indicates complete anterior and posterior fusion to the occipital bone, whereas partial fusion is incomplete in either region.[5] Among the individuals who exhibited AOF, spina bifida was recorded as absent/present (**Fig.2, panel C**).[5] Fused transverse processes and ACM asymmetry were recorded as absent/present (**Fig. 2, panels D & E**).

Figure 2. Anatomical features assessed in this study: ACM, AOF, spina bifida, fused transverse processes, and asymmetry.



Results

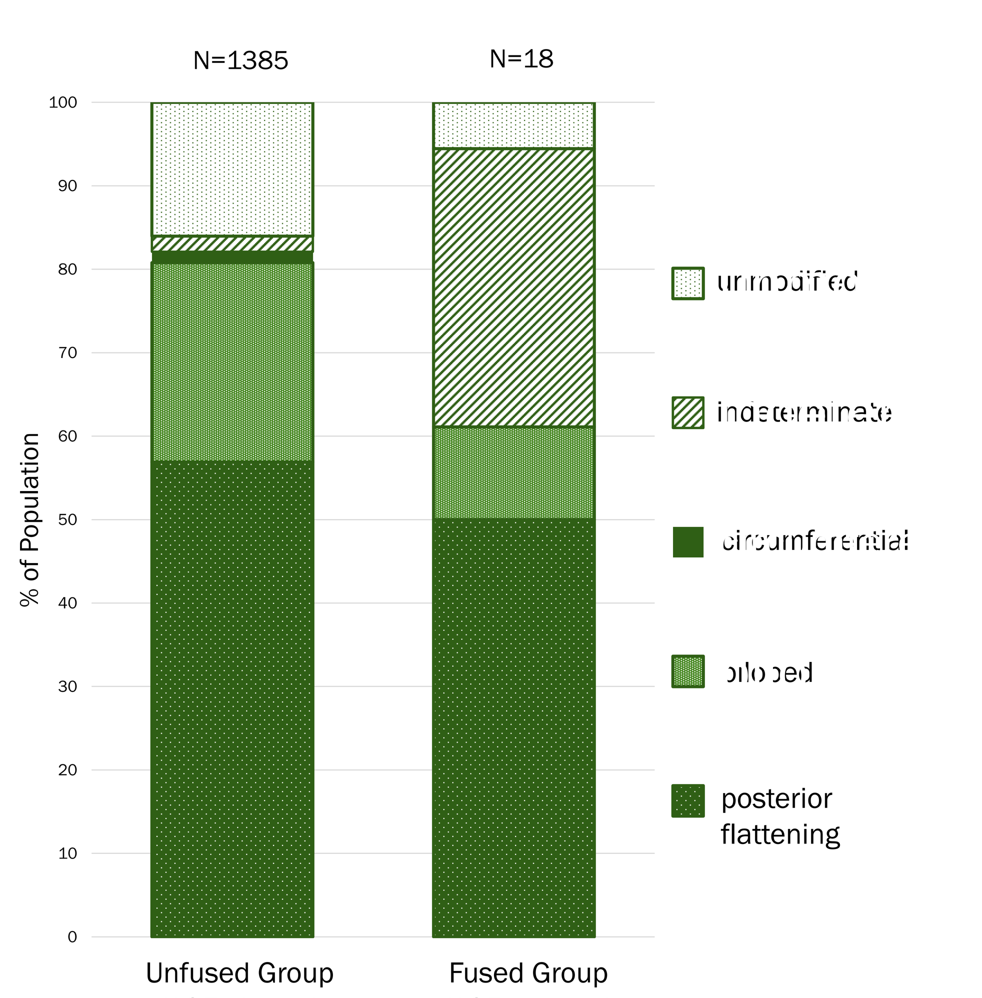


Figure 3. ACM type in fused vs. unfused groups

1 ACM and AOF

- A chi-square test showed that there is not a significant relationship between ACM and presence of AOF (N=1405, α=0.05, p= 0.23).
- A second chi-square test showed that there is a significant association between ACM type and AOF (N=1180, α=0.05, p=0.00), as shown in Fig. 3.
  - This significance is driven by a single adjusted Pearson residual, found for individuals with AOF and indeterminate ACM (a_{Bon}=0.0063, critical value=2.73, r_P=8.33).
- A Fisher's exact test (used for small sample size) showed that there is not a significant relationship between ACM and completeness of AOF (N=18, α=0.05, p=0.17).

Anatomical Differences

- Spina bifida occurred at a rate of 31.3% among individuals with AOF (N=16).
- Fused transverse processes were present in 47.4% of the fused group. 26.3% of those with AOF were fused unilaterally, and 21.1% bilaterally (N=18).
  - Fused transverse processes occurred at a rate of 50% among individuals with asymmetrical ACM (N=8) and those with symmetrical ACM (N=10).

AOF and Location

- A chi-square test showed a statistically-significant relationship between presence of AOF and location (N=1360, α=0.05, p=0.00) (Fig. 4)
- Cramer's V (0.15), which measures strength of association, indicated a weak relationship between AOF and location.
- Adjusted Pearson residuals indicated that AOF occurred significantly more than expected in Ica (a_{Bon}=0.0063, critical value=2.73, r_P=5.10).

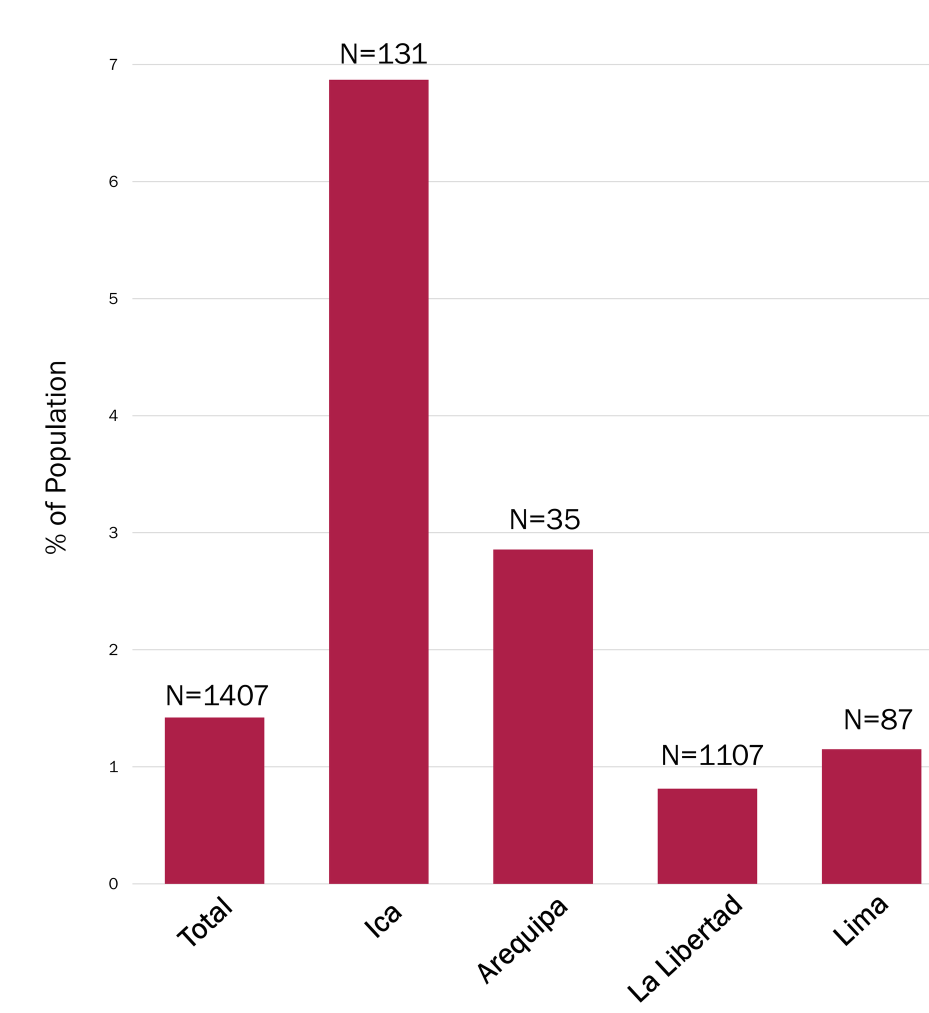


Figure 4. Rate of AOF in the total population and by department

Discussion and Conclusions

- Incidence of AOF (1.42%) falls within the range previously calculated for several global populations (0.08-3%), and is slightly higher than the global prehistoric rate (1%).[12,9]
- ACM is not one of the environmental factors that influences AOF presence or completeness.
  - Correlation between ACM type and AOF is likely due to the high number of fragments with indeterminate ACM among individuals with AOF (33.3%) (Fig. 3).
  - Genetic vs environmental etiology of AOF is still unclear.
- AOF often co-occurs with other anatomical differences of the atlas
  - Lack of postcrania makes collections comparisons limited, but rate of spina bifida (31.3%) is much higher than reported for current Peruvian populations (6.1%).[13]
  - Fused transverse processes occurred at a rate of 52.6% among individuals with AOF. Bilateral fusion of the transverse processes occurred at a rate of 26.3% overall, higher than the 10% reported for a sample of Northern Indians.[14]
- There is a relationship between AOF and location (Fig. 4).
  - AOF occurs in two previously-unreported departments along the coast: Arequipa and Ica, where AOF occurs significantly more often than expected.
  - Comparison of AOF incidence between departments is limited by low coverage of collections from Lima (2.8%) and Arequipa (54.7%).
  - AOF has been reported exclusively in coastal departments so far, with genetic or environmental implications (Fig. 1).
- **Further research** covering more departments would develop:
  - More accurate comparison of AOF incidence between departments.
  - More complete description of the geographical distribution of AOF between coastal, highland, and jungle regions of Peru.

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