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A Comparison of the Utility of Craniometric and Dental Morphological Data for Assessing Biodistance and Sex-Differential Migration in the Pacific Islands

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Background

When genetic evidence is not available for comparison of variation between populations or sexes, other heritable physical traits can be used as a proxy to do so. Genetically similar groups will exhibit similar physical traits, indicating that they have been in contact for an extended period of time, while genetically distant groups will appear physically distinct because they have not been interbreeding in the recent past. The field of biodistance attempts to reconstruct population history, access ancestry, and elucidate patterns of social organization from evidence of relatedness among human populations (Buikstra et al 1990, Pietrusewsky 2014). For example, where post-marital residence pattern biases sex-differential migration of males (matrilocality) or females (patrilocality) in a particular region, intra- and interpopulation variance in genotypic and phenotypic variation will be affected. In the Pacific Islands (Figure 1), discrepancies between maternally-inherited mitochondrial DNA and the paternally-inherited Y-chromosome suggest a matrilocal residence pattern as an effect of extended long-distance voyaging by males during Oceanic settlement (Sykes 1995, Kayser et al 2000). Craniometric measurements and dental non-metric traits offer two avenues of data for biodistance studies. However, intervening factors of environment and nutrition, in addition to sexual dimorphism, differentially influence cranial shape and size, while dental morphology is selectively neutral, not sexually dimorphic, and is unaffected by remodeling after initial development. Thus, dental traits are expected to better reflect underlying genetic variation compared to craniometrics.

Aim of Study and Expectations

The two issues of focus in this research are comparing sexes, in order to identify differential patterns of variance as a result of sex-differential migration due to residency pattern, and comparing data types, in order to determine if craniometric measurements and dental morphological variation provide comparable results in analyses of biodistance and to assess their respective uses as proxies for genetic variation in studies of migration and social organization. Increased similarity between populations will indicate increased migration for the mobile sex, females if patrilocal and males if matrilocal, while greater distance between populations characterizes the non-mobile sex. Additionally, if, as predicted, expression of dental non-metric traits bettee reflects underlying genetic variation compared to craniometric measurements, more variability will be observed in the dental data.

Materials

All dental data was scored and recorded by C.G. Turner II according to the Arizona State University Dental Anthropology System (ASUDAS) standard protocols (Turner, Nichol, and Scott 1991) based on 57 non-metric morphological traits in the maxillary and mandibular dentition. Craniometric data was obtained from the William W. Howells Craniometric Dataset and consists of 82 cranial measurements. Sample composition is described in Table 1. Dental data from five Pacific Island populations were available, including Easter Island, Fiji, Guam, Mokapu, and New Britain (Figure 1). To allow for comparison between the datasets, the same populations were utilized from the craniometric dataset.

Table 1: Total number of individuals from Turner (dental non-metrics) and Howells (craniometric) datasets utilized for statistical analysis

	Male	Female	Total
Dental			
Easter Island	110	39	149
Fiji	30	4	34
Guam	110	41	151
Mokapu	123	77	200
New Britain	92	44	136
Total	465	205	670
Cranial	Male	Female	Total
Easter Island	48	37	85
Fiji	6	2	8
Guam	32	27	59
Mokapu	54	53	107
New Britain	57	54	111
Total	197	173	370

Methods

Preprocessing – Dental traits were recorded from ASUDAS score sheets using an individual count method. Definite and probable males, as well as definite and probable females, were pooled into male and female groups, while all sex indeterminate individuals were eliminated from further analysis. Scores for the remaining individuals were dichotomized based on standard breakpoints into present and absent categories. Traits with frequencies of <10% or >90% and correlation values of 0.7-0.9 were eliminated, as were any traits that were present in one sex but not in the other after trait pruning. The craniometric dataset was utilized as is.

Distance Matrices – Mean Measure of Divergence (MMD) distance matrices were obtained from the dental data for males and females separately, as well as for the sexes pooled, using a modified script from Soltysiak (2011). An Anscombe transformation was utilized and no correction for sample size was made. Mahalanobis distance matrices based on the craniometric data were obtained in PAST (Hammer et al 2001) for all individuals of each sex, then averaged over each pairing of populations to obtain a single distance value for each comparison.

Principal Coordinates Analysis – PCo was performed in PAST for MMD and Mahalanobis distance matrices for each sex and for sexes pooled using Euclidean and Mahalanobis distances as the similarity indices for the MMD and Mahalanobis matrices, respectively. Plots of axes 1 and 2 were generated for each sex.

Generalized Procrustes Analysis – GPA was performed in Excel XL Stat using the Commandeur method of the coordinates from the first two axes obtained in PCo to generate consensus configurations for the following comparisons: Male Cranial + Female Cranial, Male Dental + Female Dental, Female Dental + Female Cranial, Male Dental + Male Cranial

Mantel Tests – Mantel tests were performed in PAST to compare the distance matrices between the groups compared in GPA, as well as the coordinates of the consensus configurations generated from GPA. Euclidean and Mahalanobis distances were used as the similarity indices for MMD and Mahalanobis matrices, respectively. Tests were run five times at 10,000 permutations and p-values were averaged.

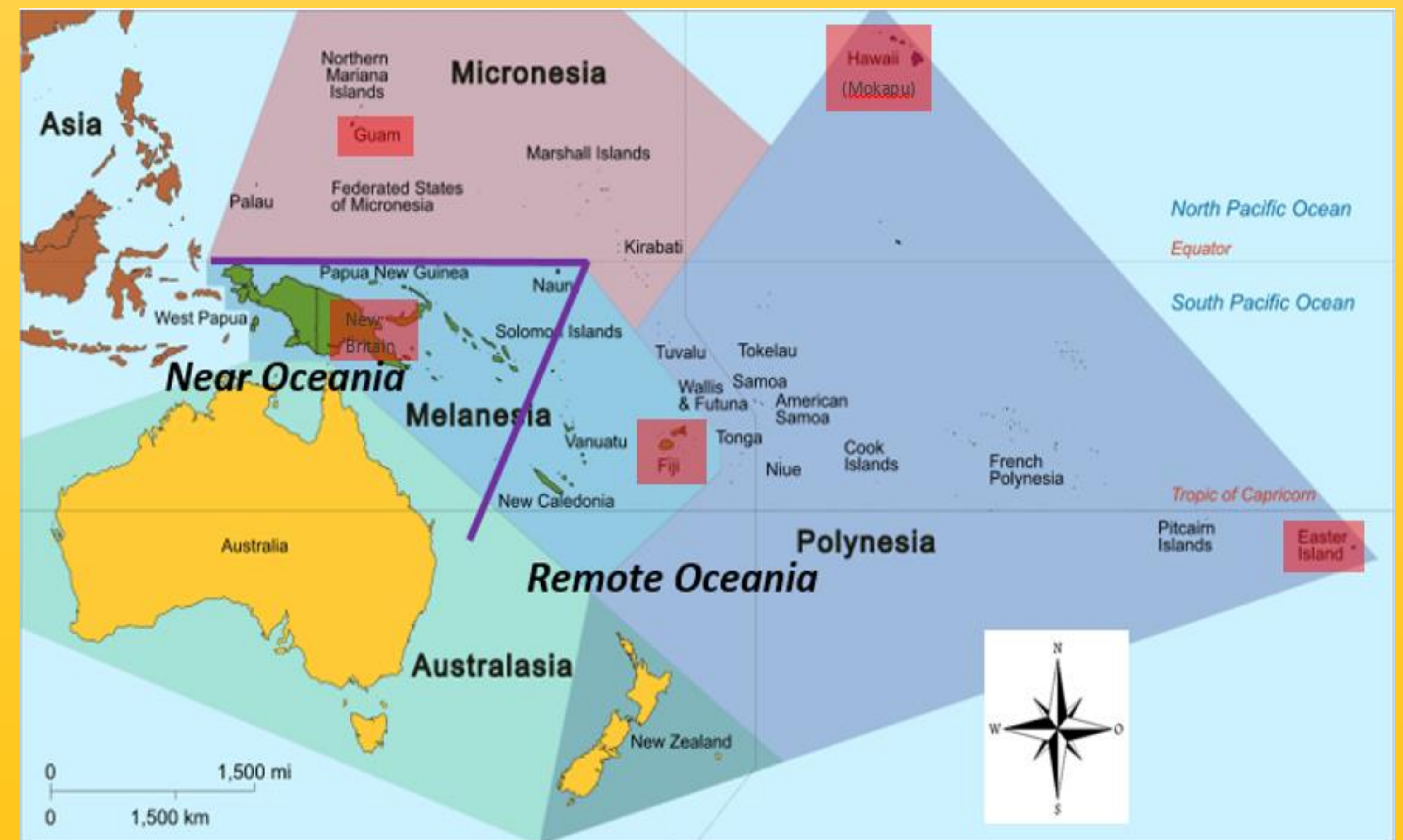

Figure 1: Map of the Pacific Islands. Sample populations are highlighted in red boxes.

Table 2: Mean Measure of Divergence (MMD) distance matrices for dental non-metric scores for males, females, and pooled sexes.

	Easter Island	Fiji	Guam	Mokapu	New Britain
Male					
Easter Island	0				
Fiji	0.244762	0			
Guam	0.341039	0.183125	0		
Mokapu	0.134372	0.122376	0.169681	0	
New Britain	0.541123	0.350469	0.283626	0.311238	0
Female	Easter Island	Fiji	Guam	Mokapu	New Britain
Easter Island	0				
Fiji	0.563286	0			
Guam	0.232979	0.465558	0		
Mokapu	0.145668	0.38711	0.141147	0	
New Britain	0.488152	0.23959	0.301724	0.278399	0
Pooled Sexes	Easter Island	Fiji	Guam	Mokapu	New Britain
Easter Island	0				
Fiji	0.246162	0			
Guam	0.275585	0.183513	0		
Mokapu	0.122233	0.171541	0.14436	0	
New Britain	0.526486	0.343899	0.279556	0.293093	0

Table 3: Mahalanobis distance matrices for craniometric measurements for males, females, and pooled sexes.

	Easter Island	Fiji	Guam	Mokapu	New Britain
Males					
Easter Island	0				
Fiji	1.45654	0			
Guam	1.39902	1.46828	0		
Mokapu	1.3969	1.46649	1.4078	0	
New Britain	1.41212	1.47237	1.42166	1.42192	0
Females	Easter Island	Fiji	Guam	Mokapu	New Britain
Easter Island	0				
Fiji	1.39288	0			
Guam	1.43064	1.39444	0		
Mokapu	1.41613	1.37619	1.41796	0	
New Britain	1.41837	1.37703	1.42178	1.40744	0
Pooled Sexes	Easter Island	Fiji	Guam	Mokapu	New Britain
Easter Island	0				
Fiji	1.46584	0			
Guam	1.41825	1.46282	0		
Mokapu	1.41385	1.45942	1.40825	0	
New Britain	1.41591	1.45277	1.41047	1.40767	0

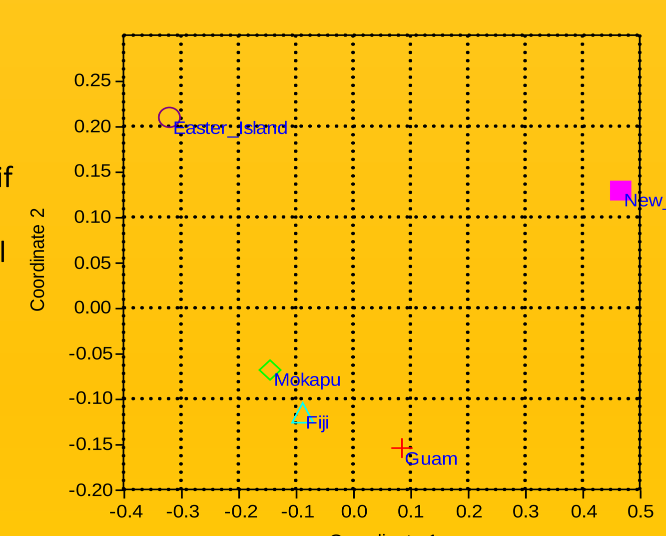

Figure 2: PCo plot of male MMD distances.

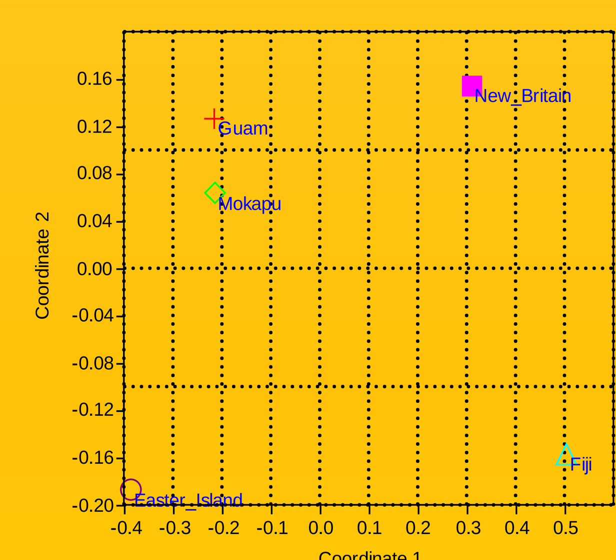

Figure 3: PCo plot of female MMD distances.

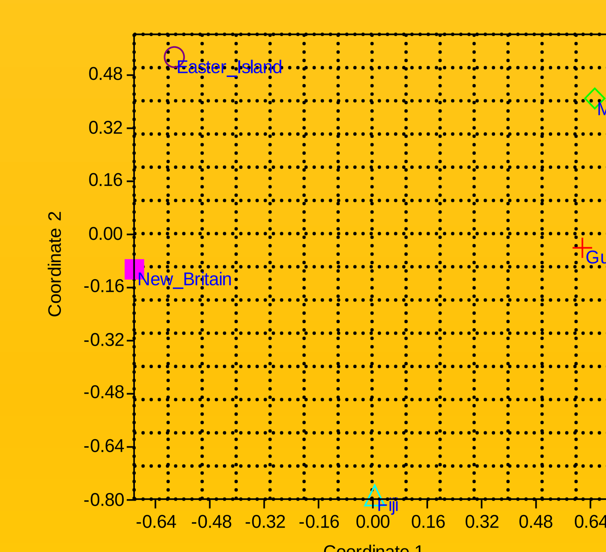

Figure 4: PCo plot of male Mahalanobis distances.

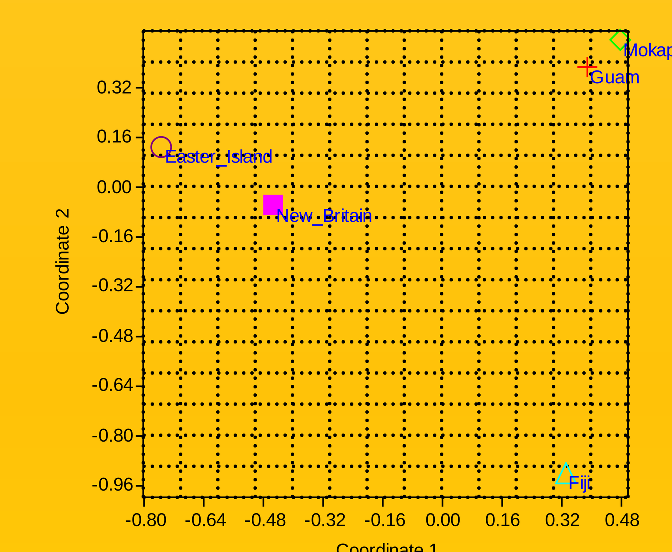

Figure 5: PCo plot of female Mahalanobis distances.

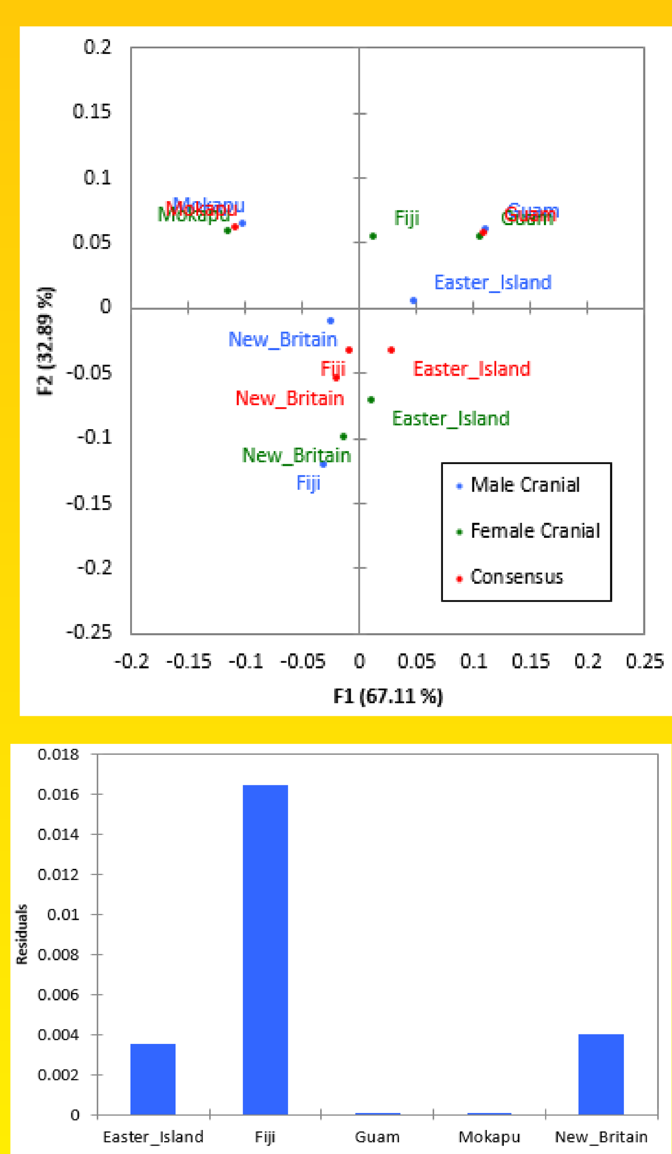

Figure 6: Male Cranial/Female Cranial consensus plots (top) and residual variance by population (bottom)

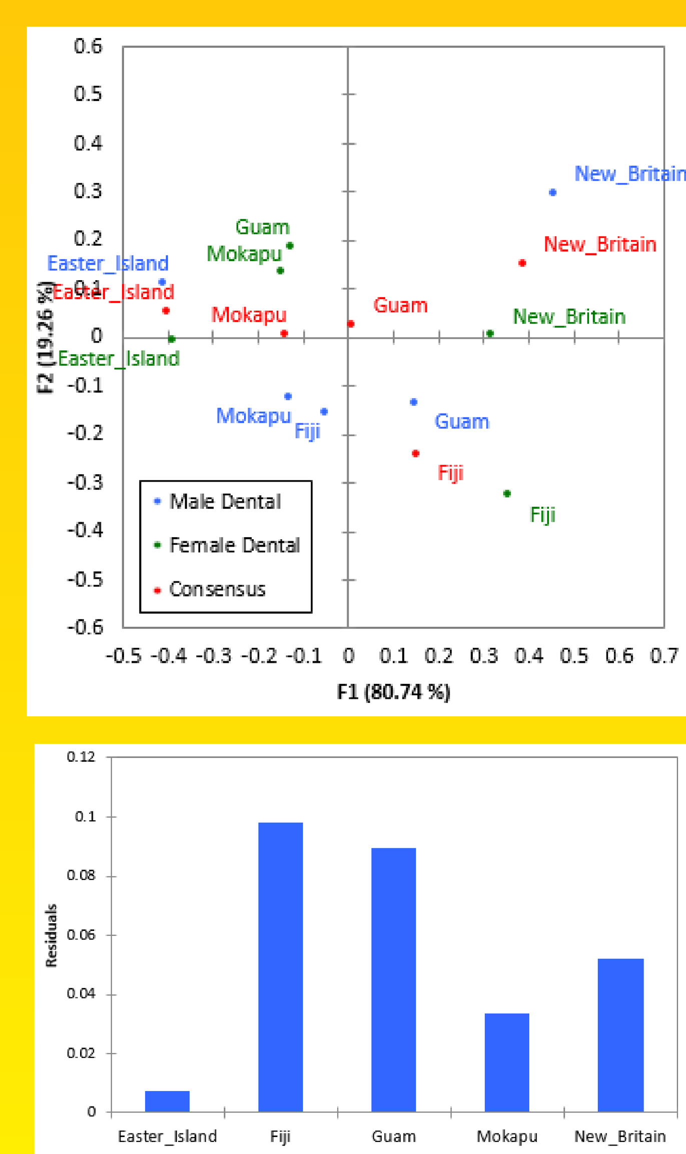

Figure 7: Male Dental/Female Dental consensus plots (top) and residual variance by population (bottom)

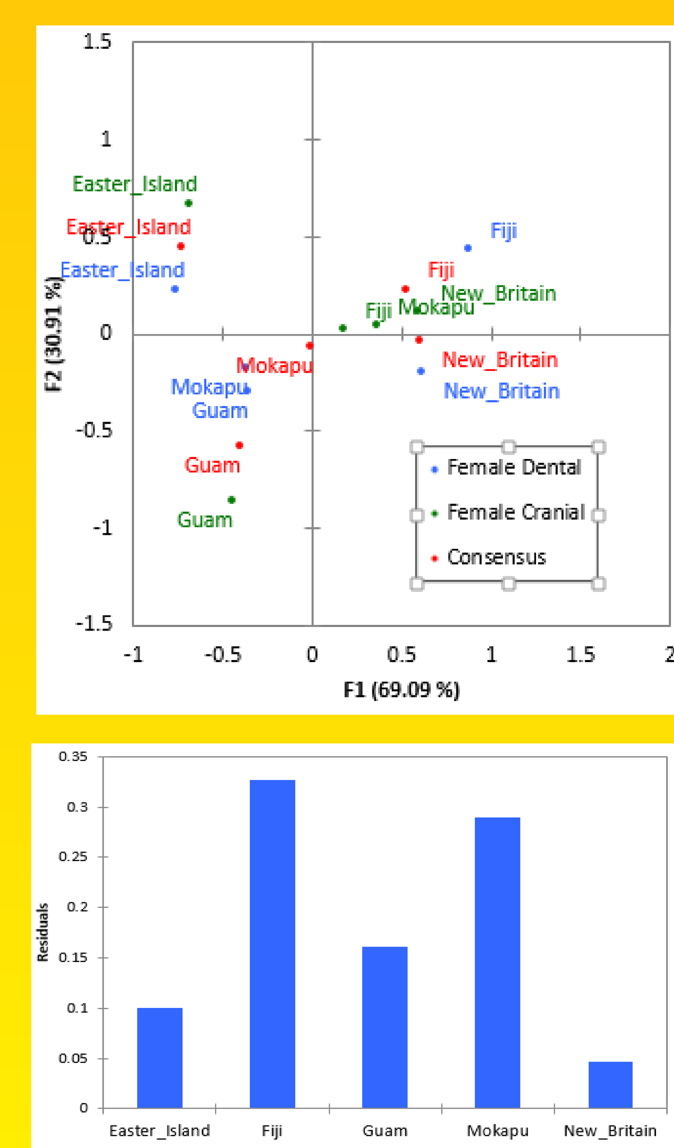

Figure 8: Female Dental/Female Cranial consensus plots (top) and residual variance by population (bottom)

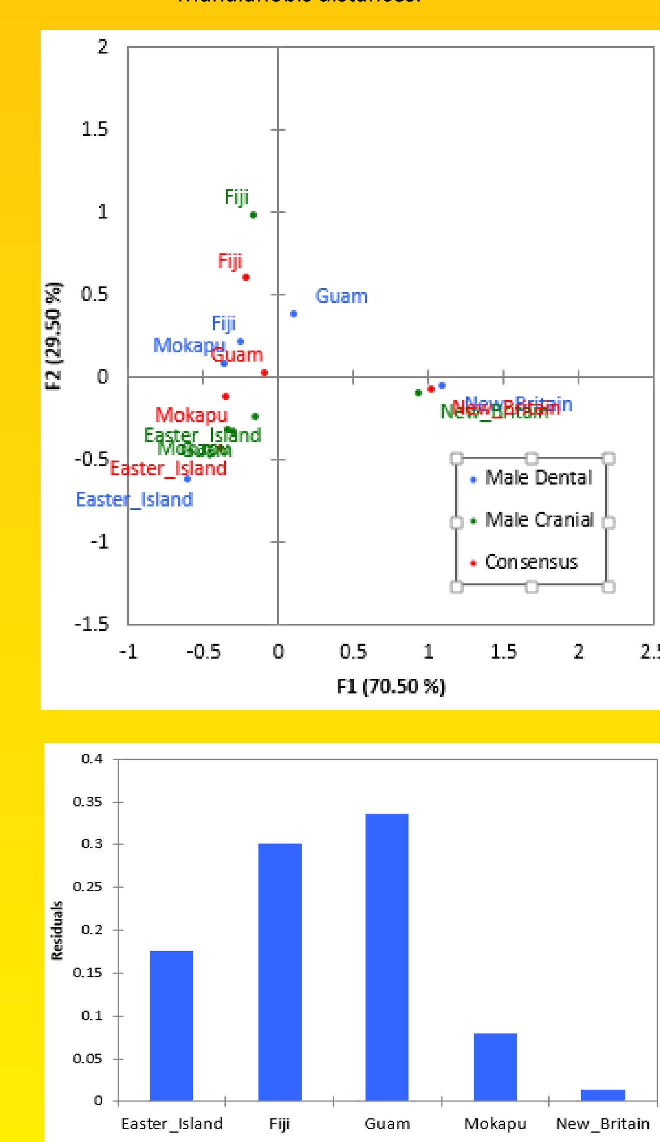

Figure 9: Male Dental/Male Cranial consensus plots (top) and residual variance by population (bottom)

Table 4: Agreement statistics (Rc) for Generalized Procrustes Analysis consensus configurations.

Data Combined	Rc
Male Cranial/Female Cranial	0.755
Male Dental/Female Dental	0.757
Female Dental/Female Cranial	0.806
Male Dental/Male Cranial	0.809

Table 5: Correlation and p-values for Mantel tests.

Comparison	R	p-value
Male Dental vs Female Dental	-0.01113	0.46932
Male Cranial vs Female Cranial	-0.345	0.93308
Male Dental vs Male Cranial	-0.06579	0.6166
Female Dental vs Female Cranial	-0.4808	0.90774
Pooled sexes Dental vs Pooled sexes Cranial	-0.3615	0.84038
Consensus Configurations for Male Dental/Cranial vs Female Dental/Cranial	-0.0696	0.58524

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Results

MMD Matrix (Table 2)

- New Britain and Easter Island are the most distant populations overall, and are more distant in males than females.
- Mokapu, Guam, and Easter Island display the least distance between them for both males and females, with more similarity between Mokapu/Guam and Guam/Easter Island for females and between Mokapu and Easter Island for males.
- Fiji is distant from Guam and Mokapu in females, but is much closer in males. Fiji/New Britain and Guam/Easter Island are similar compared to all other distances for females, while these groups are more distant in males.

Mahalanobis Distance Matrix (Table 3)

- Fiji and Easter Island are the most distant populations overall, though Fiji and Guam are nearly equally as distant. These distances are higher in males than females.
- The most distant and similar populations within each sex generally oppose each other, with distances between Fiji and all other populations greatest in males and lowest in females. Males are slightly more distant than females in comparisons of Easter Island/New Britain and New Britain/Guam, though these value are nearly equal.

Principal Coordinates Analysis

- In the MMD plots (Figures 2-3), Fiji is isolated in the females but clusters with Mokapu and Guam in the males. New Britain clusters with Mokapu and Guam in the females, but is isolated in the males. Guam plots slightly further from Mokapu in males than females.
- In the Mahalanobis plots (Figures 4-5), clusters of New Britain/Easter Island and Mokapu/Guam form in the females, while all populations are distantly spread in the males.

Generalized Procrustes Analysis

- Combinations of data types (Female Dental/Cranial and Male Dental/Cranial) have slightly higher agreement than combinations of sexes (Male/Female Cranial and Male/Female Dental), though both are above 0.7, indicating a significant reduction in original variation represented by the consensus (Table 4).
- In the Male/Female Cranial consensus (Figure 6), variance is entirely reduced, while Fiji has the greatest amount of variance left over. In the Male/Female Dental consensus (Figure 7), Fiji and Guam has the least residual variance, while Easter Island has the most. Residuals are higher overall combining data types by sex (Figures 8-9), though similar between the sexes, while the dental consensus (Figure 7) has slightly more residual variance than that of the cranial (Figure 8).
- The original and consensus coordinates plot close in the cranial consensus (Figure 6), especially those of Guam and Mokapu, while there is a greater discrepancy for Fiji. The dental consensus (Figure 7) indicates less agreement overall, with the best consensus being that of Easter Island. Combining data types by sex is moderately successful, though New Britain plots more closely in males (Figure 9).

Mantel Tests (Table 5)

- Comparisons of cranial data, females, and pooled sexes yielded negative correlations, while those of dental data, males, and consensus configurations were close to zero.
- All p-values are not significant at a 0.05-level, so the null hypothesis of no relationship cannot be rejected.

Conclusions

Overall, both the sexes and the populations of study differed more in the dental than the cranial data based on MMD and Mahalanobis distance matrices, suggesting that dental morphology is more closely representative of genotypic variation, while variation in cranial measurements is smoothed out by environmental components. Though further analysis via PCo and Mantel tests suggest that such differences are subtle and comparable over both data types, data was able to be adequately combined across sexes and data types via GPA. Analyses gave differing and often contradictory results as to which sex was more mobile, suggesting that any sex-differential migration in this region was likely subtle and that residency was closer to an ambilocal than unilocal pattern. Nevertheless, uneven sample sizes and sparse representation of this complex region give only a small insight into what is likely a multifaceted picture of migration into and throughout the Pacific Islands.

Future Directions

- Obtain larger and contemporaneous samples representing a greater number of populations, including central Polynesian, eastern Micronesian, and Southeast Asian samples.
- Utilize genetic data to clarify relationships of physical features to underlying genotypes and environmental effects.
- Compare dental non-metric scores, craniometric measurements, and genetic data from the same individuals to better elucidate their covariance within the individual.