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Rocker jaw: Global context for a Polynesian characteristic

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Running title: Global Variation of Rocker Jaw Trait

Abstract

Our goal is to describe the global distribution of the 'rocker jaw' variant in human populations. Rocker jaw refers to mandibles that lack the antegonial notch, making them unstable on a flat surface. Data were collected by C.G. Turner II on 9207 individuals from Asia, Europe, the Pacific, and the Americas, and by J.D. Irish on 3526 individuals from North and South Africa. With a focus on Polynesia, where the trait is most common, frequencies are presented for subdivisions of Oceania, Australasia, Eurasia, the Americas, and Africa. While the rocker jaw is a Polynesian characteristic, the trait is found throughout the world. Within major geographic regions, there are interesting contrasts, e.g. (1) the similarity of Jomon and Ainu and their difference from modern Japanese; (2) Aleuts and Northwest Coast Indians are similar and both are distinct from the Inuit and other Native Americans; and (3) North and Sub-Saharan Africans show a regional difference that parallels genetic and dental distinctions. Skeletons in South America that exhibit the rocker jaw have been interpreted as Polynesian voyagers who ventured to the west coast of South America. The rarity of rocker jaw in South American natives supports this view. The rocker jaw can be attributed to the unique basicranium morphology and large upper facial height of Polynesians, which highlights the integrated growth of a functional module (i.e., mastication) of the craniofacial complex. The unusually high frequency of the trait in Polynesians is a product of both function and founder effect/genetic drift.

Key words: rocker jaw, mandibular variant, Polynesia, global variation

There are two types of chairs, one that sits firmly on a base (often with four legs) and a wooden chair that sits on curved bands called rockers. Human jaws show the same contrast. In skeletal form, most human mandibles are stable on a flat surface with contact at three or four points (i.e., at the gonial angles and on the inferior surface of the body toward the anterior aspect of the mandible). As with rocking chairs, some mandibles make contact on two points about midway along the inferior surface of the mandibular body and they rock (Fig. 1).

Insert Figure 1

Houghton (1977) credits Scott (1893) as the first to describe the unusual form of many Polynesian mandibles, although Scott does not use the term rocker jaw. Several researchers in the late 19th and early 20th centuries, including Virchow, Zoja, and Toeroek were aware of this mandibular form (Weisler and Swindler, 2002). Dennison et al. (2007) note that Mollison (1908) used the term *Schaukelform* to describe this unusual (by European standards) mandibular trait. Although skeletal biologists had long been aware of 'unstable' mandibles lacking antegonial notches, Houghton (1978) says Marshall and Snow (1956) were the first to use 'rocker jaw' to describe the trait. Snow (1974) credits Rudolf Martin (1928) as the first author to use the term.

The 'rocker jaw' is generally mentioned in relation to Polynesian populations where it is common. Researchers in other areas of the world rarely consider the trait, but Snow (1974:37) notes the "rocker jaw occurs sporadically among individuals of other racial ancestry," adding that colleagues had seen such jaws in Egyptians, Hindus, Melanesians, American whites, Australians, and American Indians. Addison and Matisoo-Smith (2010:3) note that a Polynesian phenotype has a "unique combination of anatomical characteristics that are found at high frequencies in Polynesian populations: tall, robust individuals with long bodies and short legs; shovel shaped incisors; broad pentagonal-shaped crania; and mandibles possessing a broad, vertical ramus lacking an antegonial notch, giving them an unusual shape known as a *rocker jaw*." In a summary table, Gill et al. (1997) note frequencies of rocker jaw between 49-90% in five Polynesian groups. As such, most skeletal biologists in Polynesia invariably mention rocker jaw in reference to these island populations (Addison and Matisoo-Smith, 2010; Gill et al., 1997; Kam, 1971; Marshall, 1956; Pietrusewsky, 1984, 1989, 2005; Schendel et al., 1980; Snow, 1974).

Working from a base in New Zealand, Houghton (1977, 1978, 1996) has paid special attention to rocker jaw. He notes its first appearance occurs in adolescence as pre-pubescent children consistently exhibit antegonial notches; those individuals under 10 years of age do not exhibit the rocker variant. Although age plays a role in its development, Houghton (1978) found no significant difference in frequency between males and females. Snow (1974) says the trait is more common in females; in his Mokapu sample, 45% of males and 54% of females had rocker jaws. Even this difference is minor, so authors typically combine male and female observations to derive trait frequencies.

Dennison et al. (2007) show one of the mandibles from Upper Cave Zhoukoudian has a rocker jaw comparable to forms found in Polynesia. Irish has never observed the trait in African fossil hominins (including *A. afarensis* = 0 of 17; *H. ergaster* = 0 of 1; *H. naledi* = 0 of 3; *P. boisei* = 0 of 1; *P. robustus* = 0 of 3), although he does not record it in premodern individuals on a regular basis. While rocker jaw is rare in the fossil hominin record, it is evident in at least some mandibles, including Atapuerca 5, La Chapelle aux Saints, and *Homo floresiensis* (Fig. 2).

Remarkably, Irish recorded rocker jaw in 11 of 35 *Pan troglodytes* specimens (31.4%) at the Powell-Cotton Museum. All had been killed in their natural habitats (Dean and Jones, 1992; Guatelli-Steinberg and Skinner, 2000; Lukacs, 2001). Snow (1974:37) notes its presence in an ‘occasional gorilla,’ along with the Old Man from Cro-Magnon, the Mauer jaw, and Old Man 101 from Zhoukoudian (also noted by Dennison et al., 2007).

Insert Figure 2

We know that the rocker jaw trait is common in Polynesia and rare in Africa (Irish, 1993, 1998, 2005, 2006, 2016; Irish et al., 2014). Beyond that, there has never been a survey that puts rocker jaw variation in a global context. Perhaps surprising to many, these data exist but have never been published. In collecting data throughout the Americas, Pacific, Asia, and Europe, C.G. Turner II included two mandibular variables on his data sheets: mandibular torus and rocker jaw. Although he observed over 23,000 skeletons for these traits, he never published data for either variable. Scott et al. (2016) incorporated the observations of Turner in a paper on the world variation of mandibular torus. The goal here is to provide a comparable survey of rocker jaw variation based on a sample of 12,733 individuals from around the world.

Materials and methods

Trait definition

Some researchers follow a dichotomous classification for scoring rocker jaw dictated primarily by the presence (non-rocker) or absence (rocker) of the antegonial notch. For his conception of the trait, Pietrusewsky (1989) does not require that the mandible rocks, only that the anterior segment of the body curves upward at the chin; he refers to this as a ‘partial rocker.’ In some instances, this definition includes mandibles with the antegonial notch. This characterization is at odds with many skeletal biologists who work in Polynesia, and the frequencies reported by Pietrusewsky (1984, 1989) are significantly higher than those of other workers (Weisler and Swindler, 2002). Turner et al. (1991) and Scott and Irish (2017) include an intermediate category of “almost rocker” but this definition requires at least some ‘rocking.’ As Turner collected data in accordance with the classification set forth in Turner et al. (1991:26), we quote that definition to avoid ambiguity.

Grade 0: *Absent.* Lower jaw does not rock back and forth when set on a flat surface because the projections formed by the chin and distal border of the ascending rami form a tripod.

Grade 1: *Almost rocker*. The lower border of the horizontal ramus is sufficiently curved to make the jaw unstable when placed on a flat surface. Such a mandible will rock for about 1 second.

Grade 2*: Rocker.* Horizontal ramus is so convexly curved that the mandible will rock back and forth on a flat surface for several seconds.

Surprisingly, Turner et al. (1991) do not mention the presence or absence of the antegonial notch, which is considered the key trait determinant.

Materials

Rocker jaw scores of 0, 1, and 2 were tabulated from the Turner database for 9207 individuals from 129 samples, representing most major geographic regions of the world (South Asia is most significant omission). These observations were supplemented by those of Irish on 3526 individuals from 59 samples from North and Sub-Saharan Africa. All the samples listed in Appendix 1 are broken down by five major geographic groupings: Oceania, Australasia, Eurasia, Americas, and Africa.

In provenance sheets, Turner notes ten items: 1. Name, 2. Location (including longitude and latitude), 3. Date, 4. Sub-samples and collectors, 5. Cultural association, 6. Diet and environment, 7. Sample size, 8. Elements (number of maxillae and mandibles), 9. Source (usually museums), and 10. Publications. For Date, many of the skeletal samples were collected before the advent of radiocarbon dating so broad terms were used to denote time, including Recent, Historic, and Prehistoric, or some combination thereof. For samples excavated after 1952, Turner noted C-14 dates and ranges whenever possible. We do not know the precise meanings of Recent, Historic, and Prehistoric, but Recent likely denotes a sample age of 100-200 years before present (BP). Historic and Prehistoric are terms associated with initial contact with Europeans, so these times vary by region. For example, Easter Island was discovered by a Dutch explorer in 1722; samples before that date are prehistoric while samples after that date are historic. Most of the samples studied by Turner fall within the last 1000 years although some are noted as Neolithic or Mesolithic with others having radiocarbon dates >1000 years BP. In Appendix 1, the last column notes Date by the letters R (recent), H (historic), and P (prehistoric). Radiocarbon dates are provided when available.

As rocker jaw is considered a Polynesian trait, they are characterized separately. As grade 2, or full rocker, is most common in this group, chi-square values were computed to determine if males and females differed significantly for this trait. Finally, as clear patterns were evident among the 188 samples that were scored, rocker jaw frequencies for grades 0, 1, and 2 are presented in the subdivisions of the five major geographic groupings as opposed to listing data for all individual samples.

Results

Table 1 presents frequency data for the four largest Polynesian samples, plus a 'small samples-combined' tally that allows us to include information from samples where only a few individuals are represented. Chi-square values calculated from 2 X 3 tables for the five geographic groups yield no significant sex difference. This finding extends to most other samples, which allows us to combine data for males, females, and individuals of unknown sex for other world populations. For the Polynesian samples, the frequency of full rocker (grade 2) is consistently higher than the frequency of almost rocker (grade 1); the only exception is for Easter Island females where grade 1 (.400) is more common than grade 2 (.300). The trait frequency range in Polynesia is 0.403 to 0.699, with an overall frequency of 0.590.

Insert Table 1

World population frequencies for grades 0, 1, and 2 are presented in Table 2 for the five major geographic divisions. Each region is characterized individually, with frequencies also noted on a world map (Figure 3; Polynesia highlighted by larger font).

Insert Table 2

Insert Figure 3

Oceania

Rocker jaw as a characteristic trait of Polynesians is demonstrated clearly. Their frequency of 0.590 is 10 times greater than that for Micronesia (0.059). The trait is more common in Melanesia (0.210) than Micronesia.

Australasia

The frequency for Australia (0.217) is like that of Melanesia, with New Guinea slightly lower (0.137). Southeast Asia, broken down by insular and mainland groups, shows frequencies of 0.110 and 0.172, respectively.

Eurasia

The subgroups from this region that extends from northeast Asia to peninsular Europe are relatively uniform, with most frequencies falling between 0.110 and 0.186. The two exceptions are East Asia (China, Mongolia) that has a notably higher frequency (0.268) and Japan (0.027) with a much lower frequency. The European frequency (0.155) falls in the middle of the Asian population range.

Americas

Two groups stand out with the highest frequencies in the Americas: Aleuts (0.163) and Northwest Coast Indians (0.188). Except for the Eastern US & Canada (0.116), all other groups have trait frequencies under 0.100. Inuit have an exceptionally low frequency (0.035) that is in line with Southwest US, Mesoamerica, and South America where frequencies are between 0.023 and 0.057. California is slightly higher (0.087).

Africa

Rocker jaw shows a clear divide between North and South Africa. Sub-Saharan populations have low frequencies (0.048-0.102), which contrasts North African populations that have frequencies between 0.151 and 0.180.

One final note regards the range of grade 1 and 2 expressions of rocker jaw. Outside of Polynesia, where grade 2 has an overall frequency of 0.369, the range of grade 2 full rocker in the rest of the world is 0.004 to 0.106. The highest frequency is shown by the Ainu who are the only group except Polynesians where grade 2 is more common than grade 1. The world range of grade 1 expression is 0.018 to 0.209. The Polynesian grade 1 frequency of 0.221 exceeds the range for the remainder of the world. Only one group, East Asia, has a grade 1 frequency above 0.200.

To illustrate the outlier status of Polynesians, Table 3 lists the samples for world populations for total rocker jaw frequencies by 5% increments: eleven groups fall under 10% while another eleven are between 10 and 20%. Two groups had frequencies between 20 and 25% while a single group had a frequency between 25 and 30%. After East Asia, the next five 5% increments are empty; Polynesia is the only group with a total frequency between 55 and 60%.

Insert Table 3

Discussion

From an anthropological standpoint, what is the significance of a rocker jaw world survey? First, although the trait is most pertinent to Polynesian researchers, they often have no reference to global variation beyond the fact that it is uncommon elsewhere. Second, the distribution of this trait shows interesting points of population similarities and differences beyond Polynesia. Third, the great divide between Polynesians and other populations for this trait is unusual in the annals of human skeletal variation and begs for an explanation as to why this difference exists.

Polynesian population history

The peopling of remote Oceania is well attested (Bellwood, 1980; Green, 1999; Patrick, 2010; Tryon, 1984). The ancestors of Polynesians have their ultimate origins in Southeast Asia as shown by linguistics, archaeology, genetics, skeletal biology, and dental anthropology (Hanihara, 1992; Kayser et al., 2008; Kayser, 2010; Kirch 1997, 2000; Lum et al., 2002). There is, however, one caveat – American Indians in the Pacific (Heyerdahl, 1952). Was there contact between Polynesians and American Indians, especially those living on the west coast of South

America? If there was contact, was it unidirectional or bidirectional? Did American Indians venture into the vast Pacific and find one or more of the widely scattered islands and archipelagos or did Polynesian voyagers miss the islands and end up on the west coast of South America? Given their well demonstrated open ocean-going abilities, Polynesians ending up in the Americas seems more likely.

In addition to pre-Columbian chicken bones found in Chile (Storey et al., 2007), researchers have used the presence of rocker jaw in Chile as supportive of Polynesians reaching the western coast of South America. Matisoo-Smith and Ramirez (2010) examined six complete crania from Mocha Island, a small (48 km^2) island off the west coast of Chile. Using CRANID, they found three of the six crania fell in the cluster with East Asian and Pacific populations, while the remaining three crania grouped with the Americas cluster. One mandible (box 24) showed the rocker jaw form. Ramirez-Alliaga (2010:30) notes that he "viewed a Polynesian rocker jaw brought to the mainland from a prehistoric shell midden on Mocha Island, but it lacked archaeological context."

Lacking data on the rocker jaw in South America, Matisoo-Smith and Ramirez (2010) and Ramirez Alliaga (2010) could only observe that some crania found in Chile exhibited the Polynesian trait. This world survey adds an additional dimension as rocker jaw is extremely rare in South America (0.030) where full rocker incidence is 1%. This adds weight to the proposition that Polynesians reached South America. We should add that using the trait for evidence of contact between Native Americans and Polynesians is mostly a one-way street. Rocker jaws found in archaeological sites in either South or North America could provide evidence for Polynesians in the Americas. Although some dental and cranial traits can differentiate Native Americans and Polynesians, there is no single trait that would provide evidence for American

Indians in Polynesia. However, Gill et al. (1997) note that Easter Islanders have a rocker jaw frequency of 48.5%, which is significantly lower than that found in four other Polynesian groups with frequencies between 72.6 and 90.0%. They note the possibility that a non-Polynesian intrusion into the Easter Island gene pool might explain this difference. Although an interesting possibility, the data collected by Turner (Table 1) do not show a similar contrast between Easter Islanders and other Polynesian groups. Further examination is warranted, but sampling error may explain these contrasting results.

Beyond the issue of trans-Pacific contact between the Americas and Polynesia, the rocker jaw trait has been used to address other historical issues in Oceania. For example, Weisler and Swindler (2002) studied 27 crania from the Marshall Islands in Micronesia and found a frequency of 49%. They note that the "relatively high incidence of rocker jaws in the precontact people living on these Micronesian atolls adds further support to the inferred interaction between eastern Micronesia and West Polynesia suggested by shared artifact styles and linguistic similarities" (Weisler and Swindler, 2002:23). The authors may be correct given that rocker jaw is rare in other parts of Micronesia (0.059), especially Guam that forms a significant part of the Micronesian sample studied by Turner.

Given that Southeast Asia was the springboard for the peopling of Polynesia, it is surprising that rocker jaw frequencies from this area provide no harbinger of things to come in remote Oceania. Mainland Southeast Asia has a higher frequency of rocker jaw (0.172) than island Southeast Asia (0.110). Genetic analyses indicate Micronesians are sometimes closer to Polynesia and sometimes closer to Melanesia (Cavalli Sforza et al., 1994). For rocker jaw, Micronesia is not like either Polynesia or Melanesia. Unexpectedly, Australia and Melanesia have higher frequencies of the trait than Southeast Asia and Micronesia, regions with presumably closer biological ties to Polynesia.

Beyond Polynesia

For Eurasia, an interesting and not altogether unexpected finding was the similarity in rocker jaw frequencies between the Jomon (0.186) and Ainu (0.183), providing a contrast to modern Japanese (0.027) who have the lowest frequency of the trait in this region. This adds one more line of support for the dual structure model for the peopling of Japan based on dental (Brace and Nagai, 1982; T. Hanihara, 1990; K. Hanihara, 1991; Turner, 1976) and genetic evidence (Hammer and Horai, 1995; Hammer et al., 2006; Jinam et al., 2012; Omoto and Saitou, 1997; Tanaka et al., 2004).

In the Americas, rocker jaw is uncommon. There is, however, a distinction worth noting. The Inuit (Eskimos) and Aleuts share a common language family (Eskaleutian) (Krauss, 1976). Using classic genetic markers, Szathmary (1994) found the Aleut were closer to the Inuit than to any other northern Native American population although the dendrogram shows an early split between the two. Through the analysis of mtDNA, Rubicz et al. (2003) note that Aleuts are distinctive from both the Inuit and other northern Native American populations and likely represent an origin independent of both Inuit and Northwest Coast Indians. The Aleuts are indeed perplexing, given their linguistic ties and geographic proximity to Eskimo (Yupik and Inuit) populations in Alaska.

As for rocker jaw, the Inuit have a low frequency (0.036) while Aleuts have one of the highest frequencies (0.163) in the Americas. In fact, Aleuts are closer to Northwest Coast Indians (0.188) than to any other group. Based on nonmetric cranial traits, Ossenberg (1994) has long maintained that Aleuts are biologically closer to Northwest Coast Indians than to Eskimos. Using anthropometric data collected by F. Boas, Ousley (1995:427) arrived at a similar conclusion, noting that "compared with other north Pacific populations, the Siberian Labrador, and MacKenzie Delta Eskimo samples are anthropometrically closest to northeast Siberians, whereas the Aleuts are closest to some Northwest Coast Amerindians." Without making too much of this comparison, rocker jaw aligns with this position.

Although it may be a distributional coincidence, native populations in the Americas (Southwest US and beyond) with a 100% frequency of blood type O (Mourant, 1954; Roychoudhury and Nei, 1988) also have the lowest frequencies of rocker jaw at 5% or less. Areas of North America where blood type A is found, such as the Eastern US & Canada and California have slightly higher frequencies (9-12%). Fortunately for those assessing Polynesian contact in the Americas, the frequency of rocker jaw is exceptionally low in South America.

In Africa, the great divide between North and South as demonstrated by Irish (1993) for dental morphology and Cavalli-Sforza et al. (1994) for classic genetic markers is shown in rocker jaw frequencies. The trait is rare in Sub-Saharan African populations (5-10%) and more common in North African and Egyptian groups (ca. 15-18%). These predominantly Afro-Asiatic groups are more closely aligned with Europeans (16%), a finding supported by dental morphology (Scott et al., 2018) and genetics (Cavalli-Sforza et al., 1994). Irish et al. (2017) found a wide range of variation in Circum-Mediterranean groups: Neolithic-Copper Age Portugal (0/44, 0.000), Palestine (3/53, 0.057), Italy (9/72, 0.125), Turkey (4/29, 0.138), and Greece (10/33, 0.303), but the mean of 0.125 is not far removed from the overall European frequency of 0.160. Turner scored a small sample from Sri Lanka and found a frequency of 0.077 (3/39), slightly lower than most Western Eurasian samples.

How did rocker jaw become so dramatically distinct in Polynesia?

The unique morphology associated with rocker jaw is a result of morphological integration and modularity. While researchers can focus questions on specific elements (e.g., mandible) and even on specific features (e.g., antegonial notch), the mandibular morphology associated with rocker jaw is a direct consequence of inter-relationships of the craniofacial complex and how the phenotype is "an organized, integrated, functional whole" (Cheverud, 1982: 499). Functional modularity speaks directly to the interactions of traits to perform a function (Breuker et al., 2006; Klingenberg, 2008). However, because of different ontogenetic trajectories, developmental modularity can inform the resulting functional morphology (Breuker et al., 2006; Lieberman et al., 2000). To understand the developmental pathway that leads to rocker jaw morphology, one must appreciate the integration of traits required to maintain proper masticatory functions. The elements involved include the cranial base, upper facial height, and numerous features of the mandible, including the antegonial notch, or more aptly the lack of the antegonial notch.

The cranial base grows from endochondral ossification and experiences the majority of its growth in size prior to adolescence. In contrast to size, the flexure of the cranial base does not change after adolescence (Kean & Houghton, 1982; Šešelj et al., 2015). As such, the cranial base provides a foundation for cranial dimensions with later occurring developmental pathways. Specifically, rocker jaw, and other features associated with the Polynesian phenotype, are partially dependent on the basicranium (Houghton, 1978; Kean & Houghton, 1982; Lieberman et al., 2000). The cranial base does experience an adolescent growth spurt, though it is of far less magnitude since it has previously achieved such remarkable growth in infancy and childhood (Nahhas et al., 2014). The growth trajectories of the facial dimensions are in contrast to the cranial base, as their peak growth velocity generally coincides with the peak height velocity (Flores-Mir et al., 2004; van der Beek et al., 1996). During growth, the splanchnocranium is displaced in a forward and downward trajectory from the cranial base and vault. Subsequently it has been argued that these features direct other aspects of craniofacial morphology, such as facial height (Enlow, 1990; Enlow & Bhatt, 1984). Remarkably, male and female means for upper facial height in skeletally mature Polynesians is at the upper range for modern *Homo sapiens* (Houghton, 1978; Howells, 1973). The uniquely flat cranial base and the remarkably large upper facial height in Polynesians act as the underpinnings to the distinct mandibular morphology. As facial height increases in adolescence, there is a concomitant reduction in the gonial angle (Kean & Houghton, 1982). Consequently, there is a loss of the antegonial notch to help accommodate these two features and the rocker jaw morphology appears (Houghton, 1978). Large muscle attachment sites have been argued to be necessary to achieve comparable occlusal pressure of the unusually open gonial angle associated with rocker jaw morphology. While musculature was not measured, inferences to support this claim have been made through observations of muscle attachment sites on the mandible (Kean & Houghton, 1982).

We posit the ontogenetic trajectories of each element and the covariation of traits essentially leads to the rocker jaw morphology in skeletally mature individuals. And while it is not linked to mastication requirements for a specific diet (Houghton, 1977), the lack of an antegonial notch is a result of mastication being a functional module of the craniofacial complex. The high heritability rates of the gonial angle (0.57) and the cranial base (0.41) (Šešelj et al., 2015), in combination with founder effect and genetic drift, likely led to the high incidence of this unique trait in the Polynesian population. The smaller the population, the greater the magnitude of genetic drift (Mielke et al., 2011). This is supported in part by the dendrogram of

Cavalli-Sforza et al. (1994:362) that shows four Polynesian samples (Easter Island, New Zealand, Society Islands, Cook Islands) are genetically the most highly differentiated groups compared to other Pacific populations from Melanesia and Micronesia. Hill et al. (1987) also found evidence for both founder effect and genetic drift in in Eastern Polynesia for globin gene variants. Rocker jaw in Polynesia, in sum, is the outcome produced by an unusual combination of chance and functional factors.

Future Methodological Approaches

The rocker jaw morphology is theorized to result from a unique developmental trajectory that impacts numerous components of the craniofacial complex, and many of these traits have high heritability. Therefore, it seems plausible that the distinct mandibular morphology in combination with a suite of cranial dimensions could be useful to better understand human variation and even be applied in a forensic anthropological setting. Most anthropological researchers have explored human variation within a specific framework, such as only metric or only morphological variables. However, integration of numerous samples of both historic and modern individuals and of both metric (i.e., cranial) and morphological (i.e., mandibular) variables, would offer an opportunity to further explore the covariation among the potentially unique craniofacial complex. Essentially, by developing a model that incorporates the morphological data in the current study, morphological data presented by Berg & Kenyhercz (2017), and craniometric data of the same groups, one could quantify the covariation of traits and their change through time. This methodological approach would ultimately confirm or refute the role of developmental integration in the expression of the phenotype, and on more proximate levels impact our understanding of migration rates and peopling questions and even contribute to increasing the rates of positive identification for specific populations.

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This article is a contribution to the Christy G. Turner II Legacy Project. Over a 30-year span, Turner made thousands of observations on the tooth and jaw morphology of skulls housed in museums throughout North and South America, Europe, Asia, and the Pacific. Although a prolific publisher, he amassed so much data that some elements of his enormous database were never addressed. This paper on rocker jaw, as one of those missing elements, is an homage to Dr. Turner and his life's work. The senior author thanks Korri D. Turner who has been an indispensable aid in supporting and facilitating the legacy project in her father's name.

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Table 1. Rocker jaw frequencies for Polynesia broken down by sex.

			Frequency					
SAMPLE		n	0	1	2	Total	Chi-square	P
Marquesas	Male	56	0.250	0.214	0.536	0.750	4.918	0.0856
	Female	29	0.448	0.069	0.483	0.552		
	Unknown	18	0.222	0.278	0.500	0.778		
	Total	103	0.301	0.184	0.515	0.699		
Mokapu	Male	100	0.420	0.260	0.320	0.580	4.510	0.1049
	Female	56	0.250	0.339	0.411	0.750		
	Unknown	11	0.364	0.273	0.364	0.637		
	Total	167	0.359	0.287	0.353	0.640		
Tahiti	Male	34	0.676	0.147	0.176	0.323	2.854	0.2400
	Female	12	0.500	0.083	0.417	0.500		
	Unknown	6	0.333	0.167	0.500	0.667		
	Total	52	0.596	0.134	0.269	0.403		
Easter Island	Male	60	0.517	0.183	0.300	0.483	2.706	0.2584
	Female	10	0.300	0.400	0.300	0.700		
	Unknown	14	0.500	0.143	0.357	0.500		
	Total	84	0.488	0.202	0.310	0.512		
Small samples combined	Male	67	0.462	0.209	0.328	0.537	0.294	0.8634
	Female	15	0.400	0.267	0.333	0.600		
	Unknown	5	0.400	0.000	0.600	0.600		
	Total	87	0.448	0.207	0.345	0.552		
Polynesia total	Male	317	0.445	0.215	0.341	0.556		
	Female	122	0.344	0.246	0.410	0.656		
	Unknown	54	0.352	0.204	0.444	0.648		
	Total	493	0.410	0.221	0.369	0.590		

Table 2. Rocker jaw frequencies for world populations (by grade).

			Grade			
Geographic region	Subgroup	n	0	1	2	Total
	Polynesia	493	0.410	0.221	0.369	0.590
Oceania	Melanesia	362	0.790	0.130	0.080	0.210
	Micronesia	222	0.941	0.045	0.014	0.059
	Australia	552	0.783	0.134	0.083	0.217
	New Guinea	132	0.864	0.076	0.061	0.136
Australasia	Southeast Asia: insular	181	0.890	0.088	0.022	0.110
	Southeast Asia: mainland	548	0.834	0.105	0.067	0.172
	East Asia	220	0.732	0.209	0.059	0.268
	Japan	451	0.973	0.018	0.009	0.027
	Jomon	301	0.814	0.126	0.060	0.186
Eurasia	Ainu	181	0.817	0.078	0.106	0.183
	Siberia	404	0.829	0.114	0.057	0.171
	Central Asia	519	0.890	0.075	0.035	0.110
	Europe	806	0.845	0.092	0.063	0.155
	Inuit	808	0.964	0.033	0.002	0.036
	Aleut	203	0.837	0.084	0.079	0.163
	Northwest Coast	346	0.812	0.127	0.061	0.188
	Eastern U.S. & Canada	476	0.884	0.092	0.023	0.116

Americas	California	219	0.913	0.064	0.023	0.087
	Southwest U.S.	749	0.977	0.019	0.004	0.023
	Mesoamerica	262	0.943	0.053	0.004	0.057
	South America	782	0.969	0.020	0.010	0.031
Africa	North Africa: East	1549	0.848	0.105	0.047	0.152
	North Africa: West	250	0.820	0.120	0.060	0.180
	Sub-Saharan: Central	148	0.939	0.054	0.007	0.062
	Sub-Saharan: West	314	0.952	0.038	0.010	0.048
	Sub-Saharan: East	381	0.898	0.066	0.037	0.102
	Sub-Saharan: South	884	0.948	0.033	0.019	0.052

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Table 3. Geographic variation in rocker jaw frequencies by 5% increments

Range	Groups							
0-.050	Japan	Eskimo	Southwest U.S.	South America	Sub-Saharan:W			
.051-.100	Micronesia	Eastern U.S.	Mesoamerica	California	Sub-Saharan:C	Sub-Saharan:S		
.101-.150	SE Asia: insular	Central Asia	Sub-Saharan:E					
.151-.200	SE Asia: mainland	Jomon	Ainu	Europe	Aleut	NW Coast	N. Africa:East	N. Africa:West
.201-.250	Australia	Melanesia						
.251-.300	East Asia							
.301-.350								
.351-.400								
.401-.450								
.451-.500								
.501-.550								
.551-.600	Polynesia							

Appendix 1. Individual samples combined for major regional characterization with estimated ages or time period (R = recent; H = historic; P = prehistoric; BP = before present).

Region	Subdivsion	Samples	Male	Female	Unknown Sex	Total	Time period*
	Polynesia	Marquesas	56	29	18	103	2000 BP to R
		Mokapu (Hawaii)	100	56	11	167	P
		Tahiti	34	12	6	52	H
		Easter Island	60	10	14	84	H
		Small samples	67	15	5	87	N/A
OCEANIA	Micronesia	Guam	87	37	14	138	3500 BP to R
		Small samples	60	20	4	84	N/A
	Melanesia	New Britain	121	58	2	181	R
		Fiji	32	8	1	41	P to H
		New Ireland	18	6	0	24	H
		Solomon Islands	19	9	2	30	H
		Loyalty Islands	30	10	1	41	H
		Small samples	28	10	7	45	N/A
	Australia	South	47	17	2	66	P to H
		North	19	8	5	32	P to H
		Northern Territory	49	19	0	68	P to H
		Queensland	49	15	3	67	N/A
		Murry Coorang	34	13	0	47	N/A.
		Roonka	36	22	7	65	N/A
		New South Wales	96	58	9	163	N/A
		Small samples	29	12	3	44	N/A
	New Guinea	Small samples	68	55	9	132	N.A.
AUSTRALASIA							
	Southeast Asia mainland	Annam	32	6	0	38	H
		Ban Chiang	17	11	0	28	4000 to 2300 BP
		Ban Kao	14	3	1	18	Neolithic & later
		Ban Di	14	7	3	24	Neolithic, Bronze
		Burma	33	4	0	37	H
		Central Thailand	37	8	9	54	P to H
		Laos	28	5	2	35	H
		Malay composite	29	12	1	42	H to R

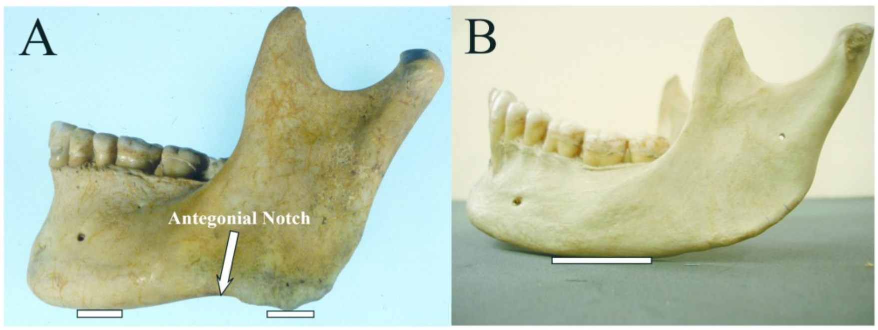
		Recent Thailand	88	61	0	149	H to R
		Bangkok	45	7	1	53	H
		Small samples	44	18	8	70	N/A
	Southeast Asia insular	Borneo	11	2	1	14	H
		Banton Island	11	9	4	24	P
		Calatagan	18	2	9	29	N.A.
		Nicobar Islands	14	4	0	18	H
		Prehistoric Taiwan	17	8	7	32	4000 to 1500 BP
		Sarawak	23	5	1	29	H
		Small samples	29	4	2	35	N/A
EURASIA	China	An-Yang	6	8	0	14	3100 BP
		China	27	1	0	28	N.A.
		North	6	0	1	7	H
		South	17	2	0	19	R
	Mongolia	Mongols	25	4	1	30	R
		Urga Mongols	51	48	0	99	R
	Tibet		22	1	0	23	H
	Japan	Hiogo	76	10	1	87	H
		Kamakura	49	16	3	68	800 BP
		Kanto	49	12	1	62	R
		Japan	113	18	2	133	R
		Recent Japan	66	35	0	101	R
	Jomon	Hokkaido	37	8	3	48	Early to Late Jomon
		Ota	22	2	1	25	Early-Middle Jomon
		Tsukumo	12	13	0	25	Late Jomon
		Univ Tokyo	115	46	24	185	4500 to 2500 BP
		Small samples	16	1	1	18	N/A
	Ainu	Hokkaido	8	7	2	17	Shellmounds & R
		Sakhalin	24	12	0	36	Shellmounds & R
		SMC	81	40	6	127	H to R
	Siberia	Baikal	32	23	3	58	Neolithic-Bronze
		Buriat	46	43	1	90	R

	Chukchi	17	1	0	18	H
	Goldi	11	7	0	18	R
	Khanty	16	23	0	39	N.A.
	Negedal	10	15	0	25	R
	Tuva	50	30	0	80	Iron Age
	Ulchi	16	9	0	25	R
	Small samples	36	14	1	51	N/A
Central Asia	Tadzhiks	11	13	3	27	2500 to 2200 BP
	Turkmen	18	17	6	41	6000 to 5000 BP
	Uzbeks	18	14	9	41	4000 to 1800 BP
	Kazaks	114	62	2	178	400 to 200 BP
	Shuravlevo	17	12	3	32	N/A
	Sopka	118	42	17	177	Bronze Age
	Small samples	17	6	0	23	N/A
Europe	Finns	26	15	1	42	R
	Kaberla	60	30	7	97	800 to 400 BP
	Karelian	60	39	3	102	R
	Lapps	45	16	0	61	R
	Reindeer Island	20	7	1	28	7000 BP
	Russian	75	42	5	122	H
	Ukraine Mesolithic	23	15	2	40	Mesolithic
	Ukraine Neolithic	68	44	5	117	6000 to 5000 BP
	Danish Neolithic	43	12	2	57	6200 to 4800 BP
	Poundbury	17	23	1	41	1850 to 1650 BP
	Netherlands: DH	27	2	11	40	1400 to 1200 BP
	Netherlands: Lent	27	6	9	42	1300 to 1150 BP
	Small samples	9	6	2	17	N/A
Inuit (Eskimo)	Alaska: Kodiak Island	45	60	0	105	3000 to 500 BP
	Alaska: Pt. Barrow	24	20	1	45	P to H
	Alaska: Pt. Hope	25	37	0	62	P to H
	Alaska: St. Lawrence Is.	52	50	0	102	P to H
	Alaska: small samples	7	17	6	30	N/A
	Canada	42	42	2	86	P to H
	Greenland	127	105	9	241	P
	Siberia: Ekven	45	35	1	81	2200 to 600 BP
	Siberia: Uelen	24	29	3	56	2000 to 600 BP
Aleut	Eastern	67	59	23	149	P to H
	Western	17	10	3	30	P to H

		USSR	15	9	0	24	N.A.
	Northwest Coast	Central Maritime	33	21	4	58	H
		Northern Maritime	73	35	7	115	P to H
		Gulf of Georgia	78	53	28	159	P to H
		Small samples	2	10	2	14	N/A
	North America	Alabama	96	54	3	153	Archaic to late P
		Arkansas	67	53	29	149	900+ BP
AMERICAS		Iroquois	50	42	82	174	500 to 400 BP
		California: North	79	48	19	146	P
			43	16	14	73	P to H
		SW US: Cibola Anasazi	51	41	9	101	P
		SW US: Kayenta Anasazi	49	29	5	83	1500 to 700 BP
		SW US: Grasshopper	40	59	1	100	725 to 600 BP
		SW US: Point of Pines	65	58	4	118	1600 to 500 BP
		SW US: Zuni	70	91	1	162	P
		SW US: Hohokam	83	71	22	176	P
		Mesoamerica: Tlatelolco	93	31	29	153	500 to 400 BP
		Mesoamerica: Cuicuilco	19	31	6	56	4500 to 1800 BP
		Mesoamerica: Guasave	18	6	7	31	N/A
		Small samples	13	5	4	22	N/A
	South America	Panama	38	24	8	70	7000 to 1000 BP
		Ayalan	28	20	21	69	2500 to 400 BP
		La Paloma	26	24	0	50	7700 to 5000 BP
		Peru	73	103	12	188	2000 to 500 BP
		Chile	65	61	19	145	3000 to 2000 BP
		Brazil: Corondo	33	20	4	57	4200 to 3000 BP
		Brazil: Sambaqui North	38	24	8	70	5000 to 1200 BP
		Brazil: Sambaqui South	48	22	3	73	4100 to 3600 BP
		Small samples	33	17	10	60	
	North Africa	East	---	---	---	1549	N/A
	North Africa	West	---	---	---	250	N/A
AFRICA**	Sub-Saharan	Central	---	---	---	148	N/A
	Sub-Saharan	West	---	---	---	314	N/A

Sub-Saharan	East	---	---	---	381	N/A
Sub-Saharan	South	---	---	---	884	N/A

* P (prehistoric); H (historic); R (recent) ; N.A. (not available)
**Males and females combined Total 12733

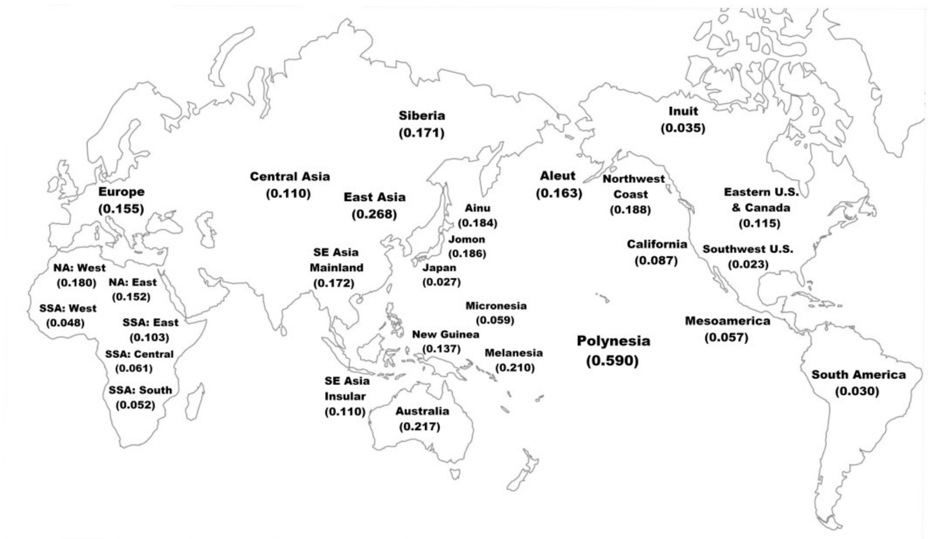


A. A non-rocker mandible that is stable on a flat surface, with clearly defined antegonial notch. B. Rocker jaw (grade 2) where inferior border of mandible makes contact on flat surface at only one point on each side of jaw; mandible lacks antegonial notch and exhibits rounded gonial angle.

297x209mm (300 x 300 DPI)

Examples of rocker jaw in the hominin fossil record. Atapuerca 5 (Middle Pleistocene); La Chapelle aux Saints (Upper Pleistocene Neanderthal); and enigmatic hominin from Flores Island.

209x297mm (300 x 300 DPI)



World map showing rocker jaw frequencies for major geographic regions; Polynesia, with exceptionally high frequency, highlighted by larger font.

296x209mm (300 x 300 DPI)