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A Protocol for Scoring Three Posterior Cranial Superstructures which Reach Remarkable Size in Ancient Mariana Islanders

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Abstract—A protocol is introduced and illustrated for the systematic scoring of three sets of cranial superstructures: (1) tubercle on the occipital torus (TOT); (2) retromastoid process (PR); and (3) posterior supramastoid tubercle (TSP). These hyperostotic traits, associated with attachments for neck, shoulder girdle and thoracic cage muscles, are distinctive in their relatively high frequencies and remarkable in their strong degrees of development in archaeologically-recovered Mariana Islander skeletal remains. This is noteworthy, as very few morphological traits of the human skeleton are population- or population group-specific. Currently, these superstructures are enigmatic in origin and somewhat obscure in geographic patterning, though markedly strong expression of them *appears* to be virtually restricted to Oceania. In order for rigorous inquiry into the etiology, development and meaning of these superstructures to proceed, further understanding of their spatial and temporal distribution is needed. Adoption of the present protocol will facilitate the production of morphologically-equivalent comparative data for populations inside and outside of Oceania.

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Introduction

Human skulls are extremely complex structurally, and manifest substantial variation in morphology both within and between populations. Such variation in skull form is epitomized in ancient Chamorros, as a significant minority of archaeologically-recovered indigenous Mariana Islanders have "unusual" bony overgrowths (superstructures) at one or more of three muscle attachment sites on the back of the skull. These superstructures are remarkable in two ways: (1) They are seldom expressed at all in non-Oceanic populations, and (2) in their *marked* state of development, they appear to cluster at highest frequencies, worldwide, in ancient Chamorros. As the present contribution describes and illustrates a method for scoring these three "unusual" superstructures, a brief consideration of the factors that determine craniofacial form is in order.

Variation in the morphology of adult skulls is rooted in a multiplicity of articulated developmental, growth and remodeling processes. There is diversity of opinion as to the factors that determine craniofacial form, but Ranly (1988, after van Limborgh 1972) has constructed a composite theory of craniofacial growth that consolidates some of the more compelling current concepts and data: Skull form is considered to be the outcome of the interplay of five sets of controlling factors: (1) intrinsic genetic factors, (2) local epigenetic factors, (3) general epigenetic factors, (4) local environmental factors, and (5) general environmental factors. Intrinsic genetic factors are those which are inherent to the skull tissues themselves, while local epigenetic factors are genetically determined influences on local craniofacial form that result from the growth and development of adjacent structures and spaces, such as the brain and eyes (see Moss & Young 1960, Moss 1971). General epigenetic factors are genetically determined influences emanating from distant structures, such as the endocrine sources of sex hormones. Local environmental factors are nongenetic influences on localized craniofacial form that originate from proximate physiologic events, such as external pressure and muscular forces (see Moss & Salentijn 1969), while general environmental factors include such factors as food and oxygen supply (Moyers 1973).

In Ranly's (1988) view, local epigenetic and local environmental factors are the primary determinants of the attained form of cranial vault, middle face, and mandible. In contrast, the morphologies of the bones at the base of the skull (which develop from cartilage models) are primarily co-determined by intrinsic genetic and local environmental factors. This theory can be extended beyond the consideration of craniofacial growth in skeletally immature individuals to cover both so-called "continued growth" in adults (see Behrents 1985), and activity-induced skeletal transformations that occur in response to physiologic loads and muscle actions (Ranly 1988).

Given the structural complexity of the human skull, reflecting its complicated morphogenetic history and remodeling potentials, it is not surprising that systematic, accurate, and precise metric and non-metric description of its form is often problematic. Difficulties of data replication, as determined from intra- and inter-observer error testing, can result from such factors as (1) insufficient rigor in the description of a specific technique for scoring or measuring the trait, (2) incongruity between the full range of morphological expression of a trait and the scoring scheme that purports to cover it, (3) skeletal landmark or feature ambiguity, (4) mechanical difficulty in making a measurement, or practical difficulty in observing a trait, (5) idiosyncratic inter-observer differences in making a measurement or scoring a trait, and (6) unwitting drift in applying a protocol over a period of time, in the case of intra-observer imprecision (see Molto 1979, Heathcote 1981).

As mentioned above, the purpose of this contribution is to introduce a protocol for the systematic description (scoring) of three quasi-continuous, nonmetric traits of the human occiput, which occur in relatively high frequencies and exaggerated states of development in ancient Mariana Islanders. The judicious application of the present protocol should obviate or reduce potential data replication problems 1, 2, 3, 5 and 6 (above).

The present method is the first tightly-defined scoring scheme for describing three unusual (from a global perspective) cranial traits that are enigmatic in origin and still somewhat obscure in geographic patterning. Expanded knowledge of their spatial and temporal distribution is prerequisite to obtaining an understanding of their meaning. Prior researchers have devised a number of systems for scoring these traits, but they are usually subjective in nature (cf. Lahr 1994:34) and concordances among them are unspecified (Heathcote, Sava, Hanson & Anderson, in prep.). While the Lahr (1994) system for scoring the occipital torus is well-defined and illustrated, it is not adopted or adapted here, as the range of global variation which she sampled did not include the two highest categories of expression in the present protocol (Marta Lahr, E-mail correspondence, March 8, 1996).

The Cranial Traits

The three quasi-continuous traits in question can be described in general terms as ectocranial superstructures (see Hublin 1988), located on the posterior cranium. By "superstructures", we mean built-up crests, ridges, eminences, tuberosities or processes associated with muscles attached to the periosteum via tendons, including flattened aponeuroses. Two of these superstructures, tubercle development on the *torus occipitalis* (Ecker 1878), at the trapezius attachment site, and the *processus retromastoideus* (Waldeyer 1909), appear on the occipital bone proper. The third, *tuberculum supramastoideum posterius* (Waldeyer 1909) is usually located immediately anterior to asterion, along the parietomastoid suture.

Acronyms used herein for these three traits are TOT, PR, and TSP, respectively. For greater readability, non-Latinized forms of nomenclature will be used, viz. tubercle on the occipital torus (TOT), retromastoid process (PR), and posterior supramastoid tubercle (TSP).

Concerning nomenclature and taxonomic priority, Ecker (1878) noted that bilateral tubercles represented one of several variations on the *torus occipitalis,* but these tubercles were not named until Hasebe (1935) referred to them as "supranuchal tubercles". We have chosen to employ the nomen TOT, rather than Hasebe's term, because non-marked TOT developments appear *at* (not above) the level of the superior nuchal line (SNL). While *marked expressions* of TOT (i.e. a score of 3 or 4; see below) extend superior to the SNL, the term "supranuchal" is somewhat misleading in reference to all degrees of TOT expression.

Hanson (1995), Sava (1996), and Heathcote et al. (in prep.) have reviewed the literature on these and related superstructures, as well as the literature on the anatomy and actions of muscle-tendon units associated with TOT, PR and TSP, and have presented critical discussions on trait etiology and meaning. Detailed comparative frequency data on the three superstructures, based on the presently reported protocol, are reported elsewhere (Heathcote et al. in prep.). The data describe samples studied to date by two of us (GMH and VJS) and colleagues Douglas B. Hanson and Bruce E. Anderson. The more exuberantly-developed manifestations of these traits appear to reach highest frequencies in adults (usually, but not always males) in certain Oceanic populations. It presently appears that *marked expressions* (scores of 3–4; see below) of TOT, PR, and TSP in populations outside of Oceania are of rare occurrence. This provisional claim is based on reviews of the literature, correspondences and discussions with numerous colleagues, and feedback from our visual presentations at conferences. We emphasize that the geographic clustering proposal is provisional, as it is based on negative evidence. Pardoe (1988:37) has appropriately cautioned, in relation to another cranial nonmetric trait with an apparent restricted distribution (inferior petrosal sinus), that ". . . something not mentioned by many (colleagues) is suggestive rather than conclusive."

In apparent stark contrast, a pooled sample (n = 101–108) of mostly Latte Period (AD 1000 – AD 1521) adult male indigenous Mariana Islanders (Chamorros or Chamoru) from Guam, Saipan, and Tinian, bear *marked expressions* (as above) of TOT, PR and TSP at frequencies of 29.7%, 39.4%, and 20.8%, respectively (Heathcote et al. in prep.). A small series from Tonga is likewise noteworthy in its strong degree of expression of these traits (Sava 1995 and n.d.).

Most of our earlier reports on the distribution and meaning of TOT, PR and TSP focused on their muscle-tendon associations, and both advanced and probed the hypothesis that biomechanical ("occupational") and ontogenetic factors were largely responsible for the formation and degree of development of the superstructures (Heathcote et al. 1991, Heathcote et al. 1992, cf. Hanson 1992). The reader should be cautioned, however, that occupational marker interpretations (see Kennedy 1989) are inherently problematic, owing to the difficulty of extrapolating specific activity patterns from markings on bone, especially given the lack of proper control samples for comparative study (Stirland 1991, Waldron 1994).

Currently, we favor a more multifactorial working hypothesis (Heathcote et al. in prep.), which suggests that an underlying, subclinical collagen abnormality may be related to these superstructures. In individuals so predisposed, a long period (with early onset) of occupationally-related strenuous use of muscles related to TOT, PR and TSP (trapezius, superior oblique, and sternocleidomastoid, respectively) may lead to repeated microtraumata at muscle attachment sites, subsequent collagen breakdown and consequent proliferative deposition of bone at these sites. Strenuous activities involved in stoneworking (cutting, dressing, moving and erecting megaliths) in Tonga and the Marianas are currently the favored "local environmental factors" in our working hypothesis on the formation of these superstructures (Sava 1996).

Associated Muscles and their Actions

Superstructural developments at the TOT site are associated with the tendinous attachments of the more medial fibers of the upper trapezius muscle (*m. trapezius occipitalis*), just above the insertion site of the *semispinalis capitis* muscle. The latter muscle may play a secondary role in the development of TOT superstructures. The upper trapezius fascicle that originates at the TOT site (two other fascicles originate from the *ligamentum nuchae*) inserts on the posterior border of the distal third of the clavicle. Collectively, these three fascicles of the upper trapezius act in drawing the clavicle and scapula backwards (in such actions as pulling and rowing), and play an indirect role in elevating the scapula. As well, the upper trapezius supports the distal clavicle and acromion of the scapula when a heavy weight is held by the hands, with the arms down at the side.

The PR superstructure site corresponds to the attachment of the superior oblique muscle (*m. obliquus capitis superior*), which arises from tendinous fibers on the upper surface of the transverse process of the atlas. The superior oblique, together with the *splenius capitis*, acts in bending the head backwards and rotating it to the same side. When acting with the *rectus capitis posterior major* and *minor*, the superior oblique serves as a postural muscle. It is of interest that Tountas & Bergman (1993) illustrate a variant slip of the *levator scapulae* connecting the vertebral border of the scapula, just above the level of the spine, to the occipital, near the site of the PR. These authors provide no data on the frequency of this morphological variation.

Finally, the TSP site is associated with the sternocleidomastoid (SCM) muscle (*m. sternocleidomastoideus*). The SCM arises from the upper part of the ventral manubrium, medial to the clavicular notch (sternal head), and from the superior border of the medial third of the clavicle (clavicular head). The superior attachment of the SCM is onto the anterior border of the mastoid process and, via a thin aponeurosis (but see below), onto the lateral portion of the superior nuchal line. The SCM draws the head forward and raises it when the body is supine. If the neck is fixed, the SCMs assist in raising the thorax in forced respiration. When one SCM acts, it tilts the head toward the shoulder on the same side, and rotates the neck to carry the face to the opposite side.

A schematic illustration of the relationships between the TOT, PR and TSP superstructures and the musculature discussed above is provided elsewhere (Heathcote et al. in prep.). Sources utilized in compiling this section include Waldeyer (1909), Davies with Coupland (1967), Trotter & Peterson (1966), Crouch (1985), Shipman et al. (1985), Cartmill et al. (1987), Luttgens & Wells (1989), Aiello & Dean (1990), Kreighbaum & Barthels (1990), and Johnson et al. (1994).

Protocol for Scoring Superstructures

The present method for scoring superstructural developments at the TOT, PR and TSP sites was initially formulated (by GMH) in 1992. This was prompted by the need to record such variation, systematically, in a burial collection from Gognga-Gun Beach, Guam (Anderson 1992), that was about to be reburied. Protocol development proceeded from selecting the most complete crania from the Gognga-Gun Beach skeletal sample. These crania were seriated, according to their degrees of expression of TOT, PR, and TSP. Such morphological sequencing of this moderate size sample allowed for the creation of a scoring instrument empirically based on specimens that may approximate the range of variation found globally in modern humans (Heathcote et al. 1995). Morphological criteria were developed along a five point scale (0–4), to define gradient categories of trait expression.

In applying this protocol, it is recommended that metrical determinations of superstructure elevation, referenced to specified "base" locales, be made with a 150mm precision dial or digital caliper equipped with a depth gauge (such as Mitutoyo model 573–221–50 or Fowler model 54–200–201). Measurements, rounded to the nearest 0.1 mm, are made by resting the base of the caliper on the vertex of the superstructure, keeping the plane of the caliper base parallel with the surrounding bone surface, and dropping the depth gauge to the specified (see Table 1) base locale.

TUBERCLE ON THE OCCIPITAL TORUS (TOT)

Table 1 presents the anatomical, qualitative and quantitative criteria for scoring presence and degree of hyperostotic development at the TOT site on the occipital torus. The occipital torus is a marked bony ridge that, in its sublime form, characterizes *Homo erectus.* In a usually structurally reduced form, it is encountered in modern *H. sapiens.* The torus is bounded by the highest nuchal line,

Table 1. Criteria for Scoring Morphological Variation at the Tubercle on the Occipital Torus (TOT) Site

TOT Score	Associated Morphology
0 =	Highest and superior nuchal lines are barely, if at all, palpable.
1 =	Highest and superior nuchal lines are clearly defined (and palpable), but torus is not present or is only incipiently-developed.
2 =	Torus clearly developed, with increased rugosity at trapezius site, but there are *no* discrete tubercles present, i.e. there is nothing to "grab hold of".
3 =	Torus is well-developed, and with discrete ("grab hold of"), projecting tubercles at the trapezius site.
4 =	Torus is well-developed, with massive, sometimes pedunculated, tubercles at the trapezius site. In a practical sense, a score of "4" (massive) is attained when the tubercle *appears* to be large enough to grasp between the thumb and index finger and so lift or suspend the cranium.

above, and the superior nuchal line, below. Tubercle development on the occipital torus, at the trapezius attachment site, represents a secondary superstructural development on top of a superstructure (the torus). Anatomy texts and atlases uniformly state that the trapezius attaches to the occipital by way of a thin aponeurosis, but the presence of stout and sometimes pedunculated tubercles in Mariana Islanders and other populations raises questions about *variable* bone-muscle interfaces between and within populations.

Reference crania of ancient Mariana Islanders from Guam and Tinian are shown in Figure 1. Their TOT ratings (Tables 2, 3) are positioned below illustrations showing trait expressions ranging from incipient (= 1) through massive (= 4) degrees of development. Here, and below, "trait absent" (= 0) specimens are not illustrated.

RETROMASTOID PROCESS (PR)

Table 2 presents morphological and metrical criteria for scoring the retromastoid process (PR), demonstrated by dissection as the insertion site for the superior oblique muscle (Waldeyer 1909). The PR occurs lateral to the *semispinalis capitis* and superior to the *rectus capitis posterior major* insertion sites. Waldeyer (1909) expressed astonishment that retromastoid processes were associated with such a small muscle as the superior oblique, but the PR that he illustrates (reprinted in Hauser & De Stefano 1989:108) is rather small by Mariana Islander standards, and it would appear that he did not investigate the muscular correlates of large retromastoid processes.

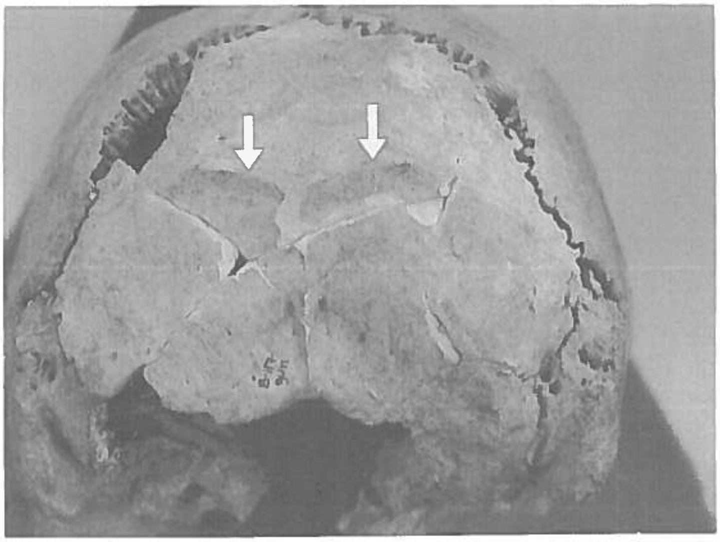
Figure 2 illustrates PR ratings (Table 2) for three reference crania and one skull of ancient Mariana Islanders from Guam and Tinian. Retromastoid process ratings reflect gradient morphological expression of the retromastoid process from incipient (= 1) through massive (= 4) degrees of development.

POSTERIOR SUPRAMASTOID TUBERCLE (TSP)

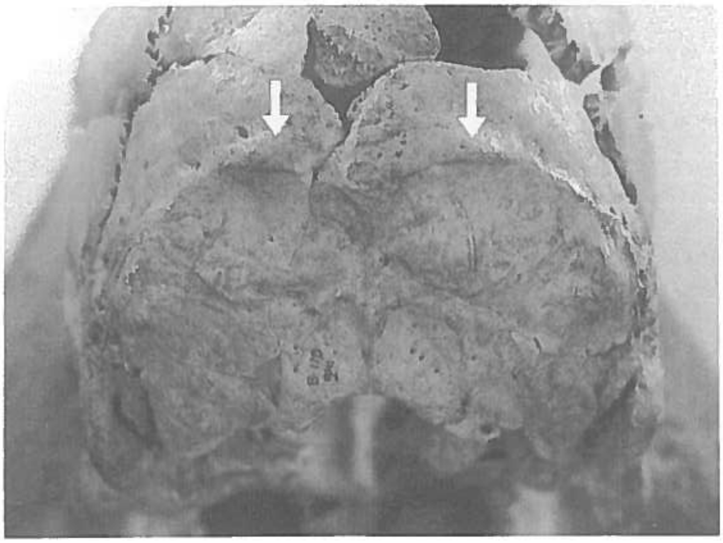
Qualitative and quantitative morphological criteria for scoring the posterior supramastoid tubercle (TSP) are presented in Table 3. In most specimens that we have examined, the TSP site is peri-asterionic, with superstructural development

Table 2. Criteria for Scoring Morphological Variation of the Retromastoid Process (PR)

PR Score	Associated Morphology
0 =	Incipient, or no, discernible elevation inferior to the superior nuchal line at the superior oblique site.
1 =	Slight mounding at this site. The mounding is < 3 mm elevation above the squamous occipital surface on the medial side.
2 =	Moderate mounding at this site. The mounding is 3–5 mm in elevation (as above).
3 =	Well developed mounding at this site, presenting as a truly retromastoid *process*. The process is 5.1–10 mm in elevation (as above).
4 =	Massive development at this site. The process is > 10 mm in elevation (as above).

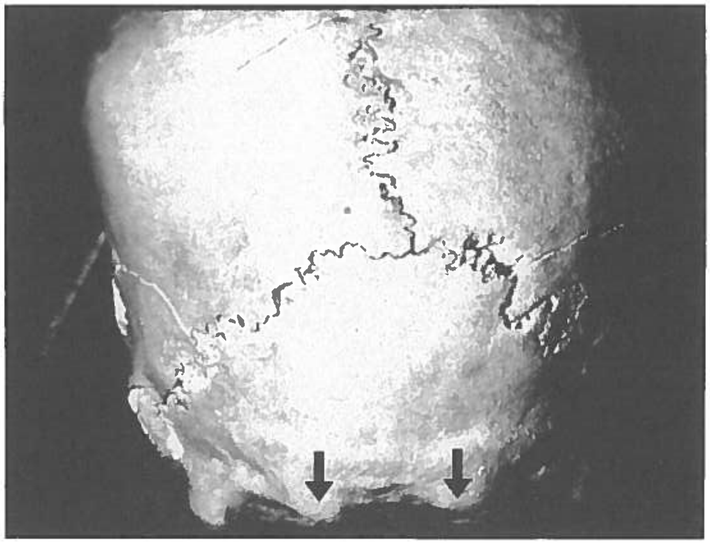


TOT = 1

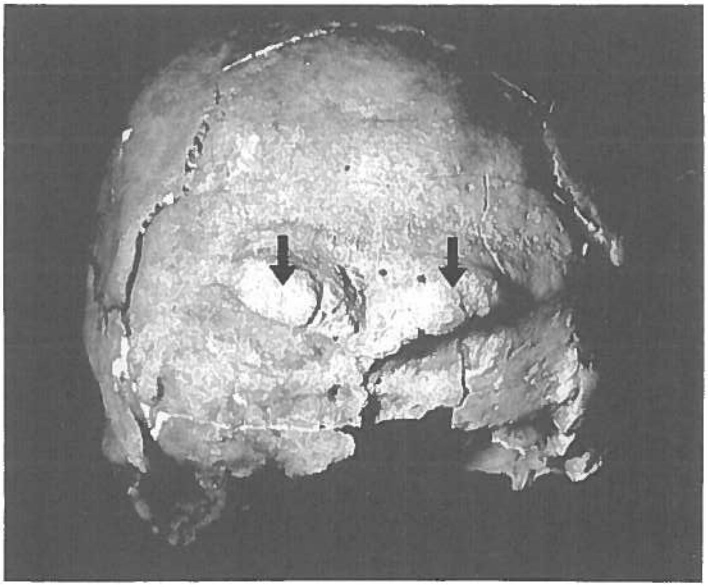


TOT = 2

Figure 1. Gradient morphological variation at the TOT site (see arrows). Archaeologically-recovered Mariana Islander crania, occipital (TOT = 4), basi-occipital (TOT = 1, 2), and supero-occipital (TOT = 3) views.

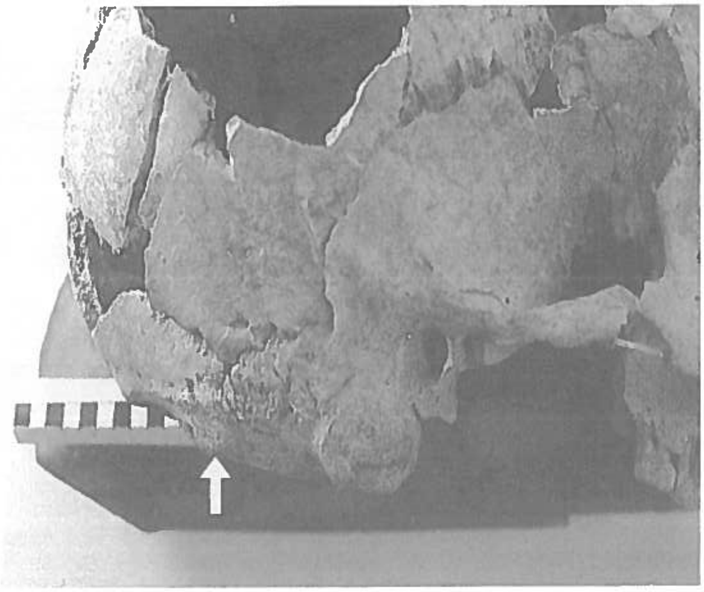


TOT = 3

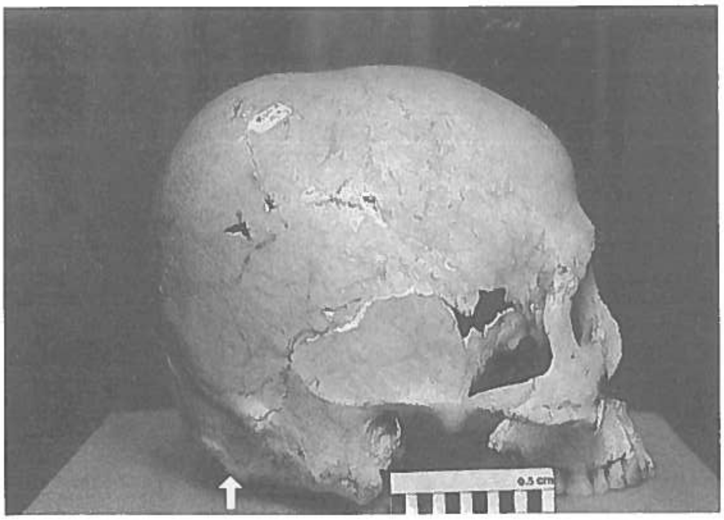


TOT = 4

Figure 1. (Continued) TOT = 1 cranium is a late adolescent male (No. B117), TOT = 2 cranium is an adult male (No. B118) from Gognga-Gun Beach, Guam. TOT = 3 cranium is an adult male (PHRI No. B1) from Camp Watkins, Guam. TOT = 4 is an adult male (PHRI No. B107) from the Hyatt Hotel site, Tumon Bay, Guam.

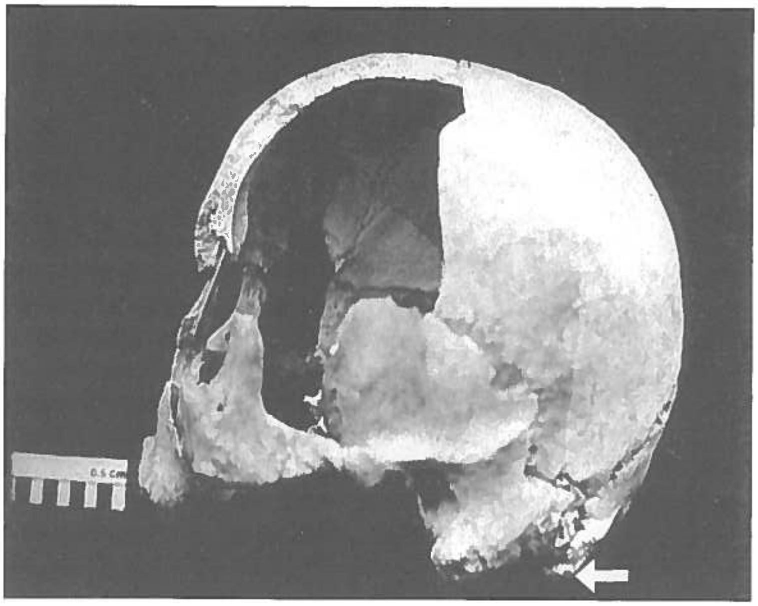


PR = 1

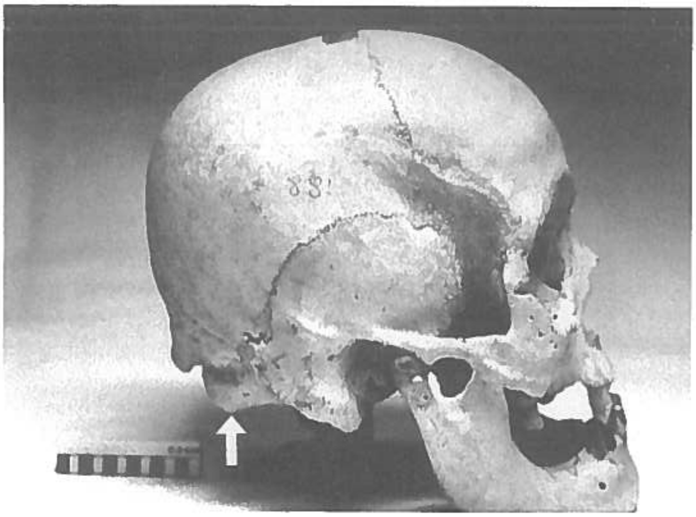


PR = 2

Figure 2. Gradient morphological variation of the PR (see arrows). Archaeologically-recovered Mariana Islander crania and skull, right lateral close-up (PR = 1), right lateral (PR = 2, 4), and angled left lateral (PR = 3) views.

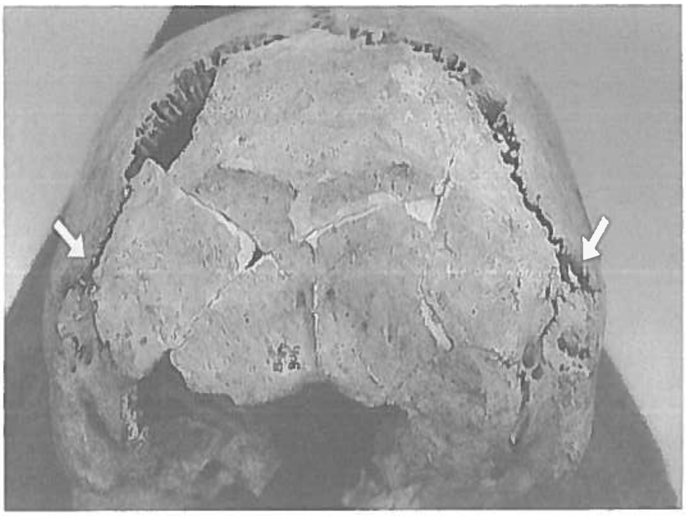


PR = 3

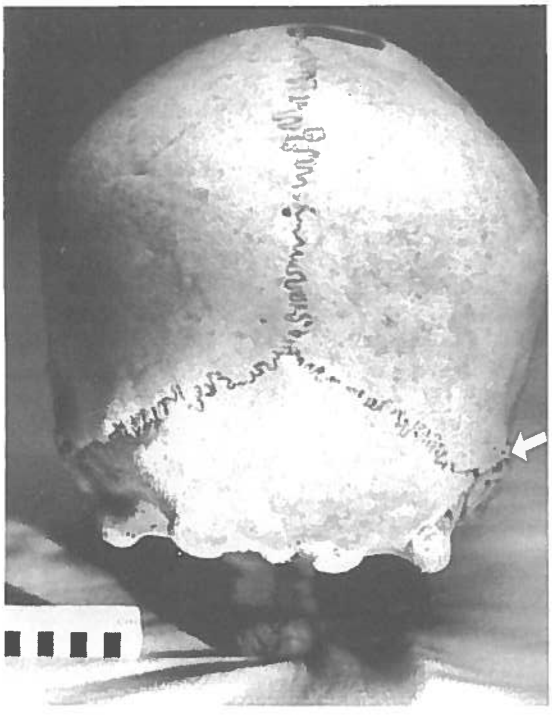


PR = 4

Figure 2. (Continued) PR = 1 cranium (No. B118), PR = 2 cranium (No. B123), and TOT = 3 cranium (No. B57a) are all adult males from Gognga-Gun Beach, Guam. PR = 4 skull (BPBM No. 881) is an adult male from Taga, Tinian.

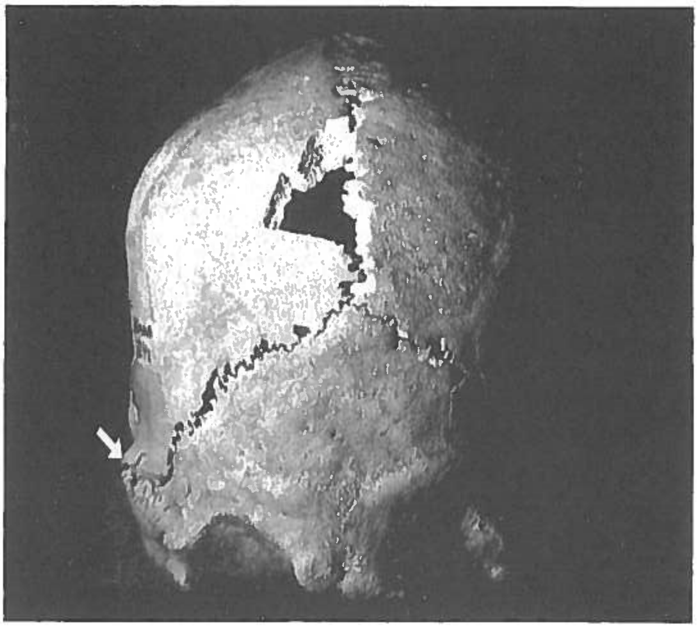


TSP = 1

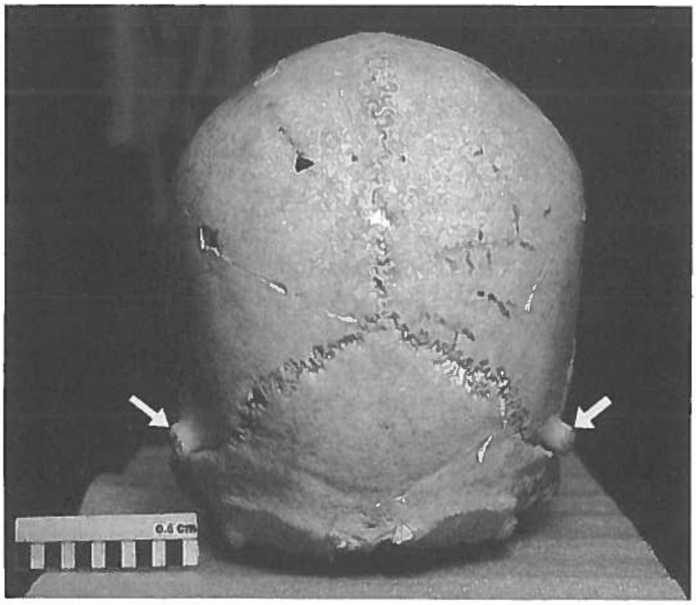


TSP = 2

Figure 3. Gradient morphological variation of the TSP (see arrows). Archaeologically-recovered Mariana Islander crania, occipito-basal (TSP = 1) and occipital (TSP = 2, 3, 4) views. TSP = 1 cranium is a late adolescent male (No. B117) from Gognga-Gun Beach, Guam.



TSP = 3



TSP = 4

Figure 3. (Continued) TSP = 2 cranium (BPBM No. 881) is an adult male from Taga, Tinian. TSP = 3 cranium (PHRI No. B42) is an adult male from Agana, Guam. TSP = 4 cranium (No. B123) is an adult male from Gognga-Gun Beach, Guam.

Table 3. Criteria for Scoring Morphological Variation of the Posterior Supramastoid Tubercle (TSP)

TSP Score	Associated Morphology
0 =	Incipient, or no, elevation of bone immediately lateral and anterior to asterion.
1 =	Slight, palpable swelling present at this site.
2 =	Moderate development, where the site appears mounded, rather than tuberculated. Elevation of the mounding is < 3 mm, measured from the parietal squamous surface immediately superior to the site.
3 =	Well developed, discrete ("grab hold of") tubercles present. Tubercles measure 3–5 mm in elevation (as above).
4 =	Massive development. Discrete tubercles are conical and pedunculated, and measure > 5.1 mm in elevation (as above).

along the parietomastoid suture, anterior from asterion. Both the mastoid angle of the parietal and the mastoid portion of the temporal are involved. In well-developed cases, the occipital bone, immediately posterior from asterion, may provide a slight contribution to this superstructure. The subtle swelling → mounding → discrete conical tubercle development at the TSP site is difficult to reconcile with anatomy texts and atlases which uniformly state that the sternocleidomastoid muscle inserts there by way of a thin aponeurosis. We suggest that such normative entheses may not have been present in individuals with well-marked TSPs.

A panel of TSP ratings (Table 3) is presented in Figure 3. The reference crania used in these illustrations are ancient Mariana Islanders from Guam and Tinian. TSP ratings categorize variant morphological expression of the posterior supramastoid process, ranging from incipient (= 1) through massive (= 4) degrees of development.

Concluding Remarks

Judging from our current compilation of novel comparative data (Heathcote et al. in prep.), limited and ambiguously concordant published data from other researchers, and personal communications with a number of human skeletal researchers, it *appears* that *marked expressions* (scores of 3 and 4, as above) of TOT, PR, and TSP are virtually restricted to Oceania. Further, relatively frequent co-occurrence of *marked* manifestations of these three superstructures appears to be much more geographically restricted: At present we know of only two population groups where such co-occurrence appears to be common, viz. prehistoric and early historic Mariana Islanders and Tongans (Sava 1995, Heathcote et al. in prep.).

Given the association of TOT, PR and TSP with neck, shoulder girdle and thoracic cage muscles, the apparent geographic circumscription of *marked* developments of these superstructures prompts the question "What habitual activity patterns, specific to populations so circumscribed, could have induced such distinctive morphological patterning?" This motor behavior hypothesis is problematic at many different levels, and is discussed at length elsewhere (Heathcote et al. in prep.). Needed alternative and complementary investigations into the meaning of these superstructures include (1) detailed head and neck dissections focusing on relevant muscle attachment sites, (2) biomechanical modelling studies, (3) experimental studies on the effects of exercise and muscle hypertrophy on both the morphology of tendinous attachments and the reactive response of underlying bone, (4) investigations into the role of nutritional factors on bone reactivity to functional stress, and (5) ancient DNA studies (see Heathcote et al. in prep.).

Production of comparative data on TOT, PR, and TSP superstructures needs to be extended beyond our current data base (Heathcote et al. in prep.), to include samples from other regions within Oceania, and from non-Oceanic populations. Furthermore, adding temporal depth to such investigations is desirable, especially if such sampling can be accompanied with concordant information from the archaeological and ethnohistorical records, e.g. bearing on chronic motor activity patterns, diet and spheres of interaction with other populations.

Investigation of the factors involved in the etiology and development of these superstructures will be facilitated by the adoption and employment of a standardized research instrument for producing morphologically equivalent comparative data. We hope that the present protocol will be so adopted and used by other investigators.

Acknowledgements

Crania illustrated in Figures 1–3 are from skeletal collections housed, or formerly housed, at the Bernice P. Bishop Museum, Honolulu (BPBM), Paul H. Rosendahl, Ph.D., Inc., Maite, Guam (PHRI), and Micronesian Area Research Center, University of Guam, Mangilao (MARC). The MARC collection, from Gognga-Gun Beach, Tumon, Guam, has since been reburied near the site of excavation. For permission to study and photograph these human skeletal remains, we thank Toni Han (BPBM), Alan Haun (PHRI), and Hiro Kurashina (MARC). Bruce Anderson (Army Central Identification Laboratory, Hickam AFB, Hawaii) and the staff osteologists with PHRI are owed a special thanks for their expert reconstruction work on the crania illustrated. Valuable advice and insights have been provided by Doug Hanson (Forsyth Institute for Advanced Research, Boston). We are also grateful for the bibliographic assistance provided by Michael Pietrusewsky (Department of Anthropology, University of Hawaii at Manoa) and Joanne Tarpley Crotts (R.F.K. Memorial Library, University of Guam, Mangilao).

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