BIOLOGICAL ANTHROPOLOGY OF THE HUMAN SKELETON

Second Edition

Edited by

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CHAPTER 9

DENTAL MORPHOLOGY

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INTRODUCTION

Dental morphology means different things to different people. Some authors consider tooth size one aspect of morphology, whereas others include shape under this rubric. I distinguish size from morphology because the methods of study and general underlying principles for each are distinct. If learning the intricacies of measuring teeth is your goal, there is a vast literature on the subject (cf. Hillson et al., 2005; Kieser, 1991). Although morphology and shape have more in common than morphology and size, shape also shows noteworthy differences (Morris, 1981, 1986; Taylor, 1969a, 1969b). Methods developed for ascertaining "tooth shape" for anthropological and forensic purposes have not been adopted widely, partly because they are difficult to replicate, diminishing their utility in comparative studies. Odontoglyphics, which is another approach to the study of tooth morphology, focuses on the complex pattern of furrows in multicusped teeth. Developed by A.A. Zubov (1968, 1977), this method involves the examination of negative relief on waxbite impressions. Although widely used in the study of Russian populations (cf. Zubov and Khaldeeva, 1979), it rarely has been used in other countries where the standard procedure is to make negative alginate impressions and positive plaster casts.

In this chapter, I focus on what most anthropologists refer to as dental morphology; that is, distinct features or traits of the crowns and roots that are present or absent and, when present, exhibit variable degrees of expression. Common examples include shovel-shaped incisors, upper and lower molar cusp number, Campell's cusp, three-rooted lower first molars, and more. My goal is to provide background and a protocol for advanced undergraduates, graduate students, and professionals who are interested in the study of dental morphological variation.

To repeat the mantra I learned in graduate school, teeth are remarkably useful in anthropological research. Their advantages include preservability (in the fossil, archaeological, and forensic records; Fig. 9.1); observability (in the living, skeletons, and fossils); variability (dozens of measurements and discrete attributes of the crowns and roots that vary within and between populations); and heritability (a strong genetic basis underlying tooth development and trait expression). Teeth also provide geographic flexibility—no matter where you go, people have teeth. Whether you are studying crown wear, oral pathology, tooth size, or crown and root morphology, if there is


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an interesting problem to pursue using teeth, all you need is an airplane ticket and a protocol.

A BIT OF HISTORY

The foundation for dental morphological research was laid by dentists, paleontologists, and physical anthropologists. Pioneers who made significant contributions to the field include Aleš Hrdlička (1920, 1921), William King Gregory (1922), Albert A. Dahlberg (1945, 1951, 1963), P.O. Pedersen (1949), C.F.A. Moorrees (1957), Bertram S. Kraus (1963), Kraus and Jordan (1965), Gabriel Lasker (1950, 1957), Kazuro Hanihara (1960, 1963), and Stanley M. Garn (1977), to name but a few. These workers focused on a number of key issues, including 1) long-term evolution of primate and hominid tooth form, 2) geographic variation in trait expression, 3) morphogenetic fields, 4) genetics and development of crown morphology, and 5) interaction between morphology and crown size and tooth number.

Despite the contributions of dentists who focused on dental morphology in the broader context of oral biology, the full potential of morphology was not realized until physical anthropologists started using crown and root trait frequencies to assess population origins and relationships. Dentists and anthropologists look at teeth through different lenses. Dentists bring their expertise in oral biology to the table when assessing crown morphology, but they are not as tuned in to the range of historical questions that can be addressed using this morphology. Anthropologists have less background in oral biology, but the mysteries of human history are their purview. Although either side may claim primacy in some areas of dental morphology, the contributions from both have been significant and syncretic and the principles that follow were developed by dentists, physical anthropologists, and scholars with doctorates in both fields.

FUNDAMENTAL ISSUES

Dental Anatomy

One item every student of dental morphology should have is a good textbook on dental
anatomy. Most texts are written by dentists who focus primarily on modal crown and root form, but some authors illustrate variations around the modal theme (cf. Kraus et al., 1969). There is, however, no better starting point than the standardized tooth (cf. Ash and Nelson, 2002).

A tooth is divided into two primary components (crown and root) and four primary tissue types (enamel, dentine, cementum, and pulp). The visible portion of the crown is covered by enamel, which is an extremely hard and durable substance that is ca. 97% inorganic. Underlying the enamel is dentine, which is a substance more in line with bone in terms of organic/inorganic composition. The pulp chamber, at the core of the tooth, is made up mostly of soft tissue (blood vessels and nerves). Cementum is the tissue that covers the surface of the root that, in concert with the periodontal ligament, anchors the tooth in its socket (Carlson, 1987; Hillson, 1986, 1996).

The primary units that constitute the crown are called cusps, whereas the primary units of the root are cones. Following the terminology of Carlson (1987), the crown of a single-cusped tooth and each cusp of a multicusped tooth are made up of essential and accessory lobes and lobe segments that, in turn, can exhibit essential and accessory ridges. Root number is defined by the presence or absence of inter-radicular projections that separate or fail to separate root cones. Often, root cones are fused together but show a developmental groove (root groove) that separates the two cones. Such unseparated cones are called radicles.

Humans and other primates have four types of teeth, and each type is represented in both the upper and the lower jaws, albeit with their own distinct morphology. The anterior teeth include spatulate incisors and conical canines. All are characteristically one-cusped and one-rooted teeth. The posterior teeth, or cheek teeth, consist of premolars and molars. Premolars usually have two cusps, although in the lower jaw, the lingual cusp of the first premolar often lacks a free apex and the second premolar frequently exhibits three cusps (one buccal, two lingual). There is no modal root number for premolars in either jaw—the first premolars have either one or two roots (occasionally three), whereas the second is mostly a single-rooted tooth. For the upper molars, modal cusp number is four, whereas modal root number is three. For lower molars, modal cusp number is five and modal root number is two. The exceptions to these normative characterizations constitute a significant part of dental morphology. As an adjunct to this basic description, refer to the Sidebar for brief definitions of terms used to describe location and direction in teeth in particular and jaws in general.

**TERMS USED TO DESCRIBE ELEMENTS OF THE HUMAN DENTITION**

**Midline**: line that follows the sagittal plane between the central incisors that divides the upper jaw and lower jaws into left and right sides

**Quadrant**: one side (right or left) of either jaw

**Antimeres**: corresponding teeth in the two quadrants of a jaw (e.g., left UM1, right UM1)

**Isomeres**: corresponding teeth in opposing quadrants of a jaw (e.g., left UM1, left LM1)

**Anterior teeth**: incisors and canines

**Posterior teeth (or check teeth)**: premolars and molars

**Upper**: maxillary

**Lower**: mandibular

**Incisal**: cutting surface of the anterior teeth

**Occlusal**: chewing surface of the posterior teeth

**Mesial**: toward the midline

**Distal**: away from the midline

**Lingual**: toward the tongue (used for all teeth)
Labial: toward the lip (used for anterior teeth)
Buccal: toward the cheek (used for posterior teeth)

Types of Traits
Morphological traits take several different forms. In Carlsen’s (1987) terminology, the general forms that subsume one to many variants are 1) lobes, 2) marginal ridges, 3) tuberculum projections, 4) occlusal tubercles, 5) cervical enamel lines, 6) root cones, and 7) supernumerary radicular structures. Not included in this classification are variants in supernumerary occlusal cusps, accessory ridges, and socket orientation.

- Lobes (or major cusps; e.g., hypocone or hypoconulid)
- Marginal ridges (e.g., shoveling, double-shoveling, or marginal tubercles)
- Tuberculum projections (e.g., tuberculum dentale, Carabelli’s trait, or protostyloid)
- Occlusal tubercles (e.g., tuberculated premolars or odontomes)
- Cervical enamel line (e.g., enamel extensions and pearls)
- Supernumerary occlusal cusps (e.g., cusp 6 or cusp 7)
- Accessory ridges (e.g., canine distal accessory ridge or premolar mesial and distal accessory ridges)
- Socket orientation (e.g., UI1 bilateral winging)
- Root cones (e.g., two-rooted UP1 or two-rooted LC)
- Supernumerary radicular structures (e.g., three-rooted LM1)

Morphogenetic Fields
In 1939, Butler introduced the concept of morphogenetic fields to the study of the mammalian dentition. He recognized three primary fields—incisors, canines, and molars. In this scheme, premolars were considered anterior extensions of the molar field. The significance of the field concept is that neither genes nor evolution act on individual teeth but on overall fields. Selective pressures to enhance the grinding surfaces of the molars, for example, impact not only the molars but also the premolars. The distal premolars of grazers grade imperceptibly into the molars. By contrast, carnivores need slicing and dicing teeth, so premolars are reduced frequently or even lost altogether in this order as are some molars (cf. Hillson, 1986; Peyer, 1968).

A.A. Dahlberg (1945) adapted Butler’s field concept to the human dentition, and the organizational principles he laid out are invaluable to students of dental morphology. He defines four rather than three fields in the human dentition by adding premolars. In considering size, morphology, and tooth number (missing or extra teeth), each tooth district (I, C, P, M) has stable and variable members. Usually, the key tooth (most stable) in each district is the most mesial member (i.e., UI1, UC, UP1, UM1, LC, LP1, and LM1, where U = upper and L = lower). The only exception to that generalization is LI2, which is more stable than LI1. The most distal member in each district is typically the most variable (U12, UP2, UM3, LP2, LM3). In the molar tooth district, where three rather than two members exist, the second molar is intermediate in variability between the mesial and the distal elements. This point is not obscure, but it is one that is relevant to the operational definitions of key morphologic variables.

Interactions Among Size, Morphology, and Tooth Number
Tooth morphology has never been linked to anthroposcopic, anthropometric, dermatoglyphic, or serologic variables. However, some relationships should be considered when studying morphological traits. The strongest correlations are between the same trait expressed on different members of a single tooth district and intra-trait— intra-field interactions. An example
would be hypocone expression on UM1, UM2, and UM3 (Fig. 9.2). To go one step more, examples of intra-trait-inter-field correlations exist, including shoveling on UI1, UI2, LI1, and LI2, which show six significant pairwise correlations (Scott, 1977a). Additional examples of significant intra-trait-inter-field correlations include *tuberculum dentale* of UI1, UI2, and UC (Fig. 9.3) and the distal accessory ridge of the upper and lower canines (Scott, 1977b, 1977c). An example of an inter-trait-inter-field relationship has been found for Carabelli’s trait and the hypocone of the upper molars (Keene, 1968; Scott, 1979). One of the few examples of a significant inter-trait-inter-field relationship is between Carabelli’s trait (UM1) and the protostylid (LM1) (Scott, 1978).

Because of consistently strong and positive intra-trait-intra-field correlations, population comparisons should focus on only one member of a field for a specific trait. Usually, the most stable member of a district should be used because trait expression on this tooth shows the highest degree of genetic control (and the least amount of environmental plasticity). Shoveling expression, for example, is best represented by UI1 as this tooth shows greater symmetry than UI2 and a broader range of variation than LI1 and LI2. In population comparisons, shoveling can be scored on all four teeth, but only UI1 shoveling frequencies should be used in a distance analysis to avoid the inclusion of redundant information. Although the key tooth is usually the best field member to represent a specific trait, exceptions
to this rule exist. For some traits, such as the hypocone of UM1 where prominent expression is the norm, it is preferable to compare UM2 hypocone frequencies as this tooth exhibits more variation in terms of total presence and degree of expression.

**Dental Genetics**

In the 1950s, when dental morphology was gaining momentum in anthropological studies, some authors believed that discrete crown traits might have simple modes of inheritance (Lasker, 1950). Kraus (1951) and Tsuji (1958) studied Carabelli's trait in families and found parent–offspring segregation patterns consistent with simple autosomal codominant and dominant inheritance, respectively. The ramifications were exciting. If crown trait frequencies could be reduced to gene frequencies, the population genetics models of Wright–Fisher–Haldane could be applied to the teeth of extant and extinct populations. In the 1960s, Turner (1967, 1969) did exactly that when he converted phenotype frequencies to presumed gene frequencies for prehistoric and living Hopi Indians and Koniag Eskimos and for living Europeans. His goal was to compare living and prehistoric populations to estimate the level of European admixture in the modern Native American groups.

In the 1970s, additional attempts to corroborate or refute simple genetic models of inheritance for crown traits led workers down a different path. Given the nature of dental morphological expression, where traits can be absent, slight, moderate, large, and so on, one could test simple models of dominant-recessive inheritance only under a certain set of assumptions. For example, one had to assume that trait absence represented one homozygous genotype. For trait presence, the assumption was that intermediate expressions were associated with heterozygous genotypes, whereas pronounced expressions were associated with the dominant homozygous genotype. These assumptions required a substantial contribution from the environment to smooth out the range of variation of the two genotypes for trait presence.

In pondering the question of how environmental factors could influence trait expression, Grünberg's (1952) model of quasicontinuous variation became the more parsimonious explanation for the nature and inheritance of morphological traits. The quasicontinuous model holds that some discontinuous traits have continuous genotypic distributions with underlying (absent) and visible (present) scales separated by a physiological threshold. Inheritance under this model is polygenic with genes at many loci interacting to produce the final phenotype. Edwards (1960) noted that many medically significant traits such as cleft lip/palate, pyloric stenosis, and spina bifida, which were traditionally thought of as simple Mendelian traits, were quasicontinuous variants with complex modes of inheritance. Even though they were not Mendelian traits, they simulated the behavior of simple inheritance models.

In analyzing segregation patterns of six traits in 53 American white families, Scott (1973, 1974) found two that conformed to simple models of inheritance. Carabelli's trait segregated like a simple Mendelian dominant, whereas cusp 7 followed a pattern consistent with autosomal recessive inheritance. On closer examination, it was found that low-frequency traits in general (e.g., cusp 7) followed segregation ratios consistent with or close to the expectations of recessive inheritance, whereas high-frequency traits (e.g., Carabelli’s trait) simulated simple Mendelian dominant patterns. As total trait frequency in a population should not have anything to do with inheritance patterns, a closer perusal of the data suggested that morphological traits, which also show a high correlation between total trait frequency and degree of expression, were threshold dichotomies (Wright, 1934, 1968) with complex modes of inheritance, not point dichotomies with simple modes of inheritance.

One of the more telling lines of support for the quasicontinuous model comes from the distribution of shovel-shaped incisors in
Indians of the American Southwest. This trait attains or approximates a frequency of 100% in living Southwest Indian groups. When the distribution of graded trait expressions is plotted, it approximates closely a normal curve, which is the precise expectation one would have when a quasicontinuous variant becomes a continuous variant (Scott and Turner, 1997). In 1977, Harris tested genetic models on a wide array of crown traits in Melanesian families and concluded these traits were quasicontinuous variants with complex modes of inheritance.

Kolakowski et al. (1980) and Nichol (1989, 1990) applied methods of complex segregation analysis to the problem of morphological trait inheritance and found some indications that major genes are involved in the inheritance of some traits. However, even if traits have major genes underlying their development, it is still not practical to tease these genes out and to reduce trait frequencies to gene frequencies. From a practical standpoint, the ramifications of dental genetic studies are as follows:

- Twin and family studies indicate dental morphology has a strong heritable component.

- Inheritance is not simple, so traits cannot be reduced to gene frequencies.

- For quasicontinuous traits, the best way to characterize a population is through the use of total trait frequencies. As total trait frequency represents the threshold separating trait absence from trait presence, this one number specifies the entire continuous and normal distribution of the genotypic variation underlying trait expression (Falconer, 1960).

- In population studies, either total trait frequencies or frequencies defined by breakpoints (e.g., individuals showing grade 3 or higher/total number of individuals) are equally useful parameters for characterizing the genetic variation underlying trait expression in a particular group.

METHODS

Trait Classifications

The collection of data on crown and root morphology begins with operational definitions of trait expression. These definitions focus primarily on the precise location of the trait and its range of variation in size and form. Early workers often scored only obvious and pronounced trait expressions. The problem with this approach is that observers often disagreed over what constituted obvious and pronounced expressions.

In his classic paper on shovel-shaped incisors, Hrdlička (1920) appreciated the problems inherent in ill-defined trait definitions. Shoveling was clearly not just present or absent. Marginal lingual ridges ranged from absent to pronounced, but between these extremes, many gradations existed. Hrdlička ultimately arrived at a four-grade classification: 1) no shovel, 2) trace shovel, 3) semi-shovel, and 4) shovel or full shovel.

In 1956, A.A. Dahlberg released a series of standardized plaques from the Zoller Clinic in Chicago that were intended to bring order and consistency to the study of morphological variation in human populations. One of these plaques codified Hrdlicka's four-grade shoveling scale. For other variables, such as Carabelli's trait and the protostylid, Dahlberg developed scales with more grades of trait expression. The Carabelli's plaque, for example, had absence (grade 0) and seven degrees of trait presence (from very slight grooves and pits to large free-standing cusps). The protostylid plaque included absence, buccal pits (grade 1), and five degrees of positive expression. For the hypocone, four grades of expression were codified as 4, 4−, 3+, and 3.

Building on the pioneering efforts of Dahlberg, Christy G. Turner II released two standard plaques for cusp 6 and cusp 7 in 1970. These traits represented the first step in what would become the Arizona State University Dental Anthropology System or ASUDAS (Turner et al., 1991). Turner, in
concert with his students, developed an extensive series of trait classifications that included not only crown traits but also root traits. In collaboration with ASU, Dahlberg sent his original plaques to be duplicated and distributed along with the new ASU trait classifications. Turner et al. (1991) provide a summary of the entire set of classifications developed at Chicago and ASU. These plaques have been distributed throughout the world and are often employed in the study of living, prehistoric, and fossil hominid populations.

I developed several ASU standard plaques (shovel U11, U12; tuberculum dentale U11. UC; distal accessory ridge UC, LC; multiple lingual cusps LP1, LP2) as part of my dissertation (Scott, 1973). The principles in setting up a trait classification are as follows:

- Find a distinct trait. This can take the form of a supernumerary occlusal cusp, an accessory ridge, a marginal tubercle, etc.
- This trait should be expressed in a consistent manner on all members of a tooth district (in some cases, between tooth districts as well, e.g., accessory ridges on occlusal surface of premolars).
- Once a trait is isolated, its variation should be examined in numerous casts and skeletons representing geographically diverse populations.
- When the full range of expression has been sampled, find teeth that express absence and the most pronounced degree of trait expression.
- After the lower and upper boundaries have been established, find additional examples that gradually increase in expression from grade 0 (absence) to maximal manifestation (grade X), making some effort to keep the grade differences approximately equal (Fig. 9.4).
- The number of grades for a specific trait is dictated by its overall range of expression, e.g., premolar mesial and distal accessory ridges vary to a modest degree; in this case, absence and three degrees of presence are adequate. For a trait that shows a large range of expression, such as shoveling, more grades are called for (anywhere from five to seven as a rule).
- Use examples from the specific tooth you are interested in, not just examples from the tooth district where the trait is expressed. The ASUDAS hypocone plaque includes expressions of this trait on UM1 and UM2, and this has required workers to adjust their observations. To avoid such adjustments, each upper molar should have its own plaque for hypocone variability.

The Hrdlička classification for shovel-shaped incisors provides an object lesson for a pitfall to avoid in setting up a standard plaque (see Fig. 9.5). Data on American Indian shoveling collected on the basis of the Hrdlička-Dahlberg scale shows a distribution that is strongly skewed to the right. Typically, the full shovel category ranges from 75% to 95% with correspondingly small values for trace and semi-shovel and basically no absence expressions. After I developed an eight-grade scale for shoveling and used it as the basis for

Figure 9.4 Ranked scale for canine tuberculum dentale; note the absence of trait for grade 0 and the pronounced expression of tubercle on grade 7. Intermediate ranks approximate even spacing between any two grades. Only left upper canines were used in this classification.
Collecting data on Southwest Indian tribes, a different picture emerged. With absence and pronounced shoveling (grade 7) framing the overall pattern of variation, the distribution of shoveling in American Indians went from strongly skewed to approximately normal (Scott, 1973; Scott and Turner, 1997).

Another practice to avoid in trait classifications is the use of different manifestations of a single trait as separate variants. A.C. Berry (1976) adopts this approach for Carabelli's trait where she lists "Carabelli's pit present" and "Carabelli's cusp present" as two separate variables. She also considers "groove pattern Y on molar 1" and "groove pattern X on molar 1" as separate traits. Each trait should be represented only once in a population analysis and on a single member of the field it occurs in. That is, any given individual should have only one grade of Carabelli's trait, and for distance analysis, only the trait frequency on UM1 should be used.

Crown and Root Traits

The following set of traits can be used as a starting point in any population study. The addition or subtraction of variables from this list should be dictated by the problem at hand. The classifications of most traits, with descriptions of each grade, can be found in Turner et al. (1991). Here, I provide a brief characterization of each variable along with some cautionary notes.

Maxillary Incisors

UI1 winging. This trait is one of the few morphological characteristics that is not reflected directly on a crown or root. Instead, winging is dictated by the orientation of the upper central incisor sockets (Dahlgberg, 1959). Rather than presenting a flat or slightly parabolic surface, the distal border of the labial faces of the central incisors are rotated outward (Fig. 9.6).

Winging, a frequent trait in Asian and Asian-derived populations (especially American Indians), is not a function of anterior tooth crowding. In all but a few instances, genetically based bilateral winging can be distinguished readily from cases that result from crowding (typically, these are much more asymmetrical). A substantial range of variation occurs from slight winging to pronounced bilateral winging, but this has not been codified on a plaque. Minimally, an observer should classify the trait as absent, slight, moderate, or pronounced. Counter-winging, where the distal borders of the incisors turn in rather than out (Dahlgberg, 1963), is not as useful as bilateral winging because this condition is often the result of crowding.
Shoveling. Technically, the descriptive term for this trait should be lingual marginal ridging (Fig. 9.7). More precisely, this single trait could be considered two separate, albeit highly correlated traits. That is, it is the combination of lingual ridges along the distal margin and mesial margin that form shoveling. Ordinarily, if you have a large mesial...
marginal ridge, you will also see a large distal marginal ridge on the same tooth. However, in populations with low frequencies of shoveling, some individuals may have incisors with one ridge (usually distal) but not the other. Mizoguchi (1985) observed these ridges separately and found interclass correlation coefficients of 0.4788 for males and 0.9167 for females. Given the extensive data already available for shoveling, it would be impractical to go back and reanalyze populations by separate mesial and distal marginal ridges.

For making observations on shoveling, the classic four-grade scale of Hrdlička (1920) and Dahlberg (1956) has largely been replaced by the two eight-grade scales of the ASUDAS (separate plaques for UI1 and UI2). Some workers have had success in treating shoveling like an interval scale trait by measuring the depth of the lingual fossa. This approach, pioneered by Dahlberg and Mikkelsen (1947), has been adopted with some success by several later workers (Aas, 1979; Aas and Risnes, 1979; Mizoguchi, 1985). This method is most applicable to the study of young individuals with unworn dentitions.

Double-shoveling. Lingual marginal ridge development is the primary characteristic of shoveling, whereas labial marginal ridging is the hallmark of double-shoveling. These ridges are never as pronounced as the lingual ridges, but the ASUDAS plaque has absence and six degrees of trait presence. Mesial and distal marginal ridges on the labial face of the incisors are often asymmetrical, with more and greater expression on the mesial marginal ridge. Snyder (1960) used the phrase “3/4 double-shoveling” to denote cases of teeth that exhibited both lingual ridges and mesial marginal labial ridges but not distal marginal labial ridges.

These cingular derivatives take the form of either ridges or tubercles, both of which can vary from slight to pronounced. Another aspect of this trait’s variation is the number of ridges, especially on UI1 but also UI2, where one, two, or three ridges might be expressed. This trait is exhibited in a myriad of forms involving degree of expression and number, so additional work is required to standardize observations.

Despite difficulties in standardization, this trait is relatively common in European and European-derived populations, making it one of the few positively expressed traits found in this geographic group. Fossil hominoids and hominids, especially Neanderthals, often exhibit basal tubercles and lingual ridges making an evaluation of their evolutionary significance a fruitful research topic.

**Interruption grooves.** Along the lingual marginal borders or basal eminence of UI1 and UI2, one can find developmental furrows that some call coronal-radicular grooves because they involve both the crown and the root (Fig. 9.8). However, in many cases, the grooves occur along the marginal ridges so the term “interruption groove” has more general application. The classification of this trait focuses on location (mesiolingual, distolingual, or both) rather than on degree of development (Turner et al., 1991).

**Maxillary Canines**

**Tuberculum dentale.** This trait, which was discussed for the incisors, is also expressed on the upper canines (Scott, 1977b). Although the canine can exhibit ridges, expression more often takes the form of slight-to-pronounced tubercles on the basal eminence. In some cases, these tubercles have free apexes.

**Distal accessory ridge.** This extra ridge is expressed on the lingual surface of the upper canine between the essential ridge and the distal marginal ridge. It is one of the few traits that shows a significant male–female difference in frequency and degree of expression (Scott, 1977c). It also wears off fairly quickly,
making observations of this trait difficult in middle-aged adults.

*Bushman canine.* To avoid geographic designators, Turner et al. (1991) refer to this variable as the canine mesial ridge. Nevertheless, the Bushman canine is used widely. This trait is related closely to the canine tubercle, which occurs commonly among the Bushmen (Morris, 1975). It is considered present when the mesial marginal ridge intersects and joins a dental tubercle without a developmental groove separating the two features.

**Maxillary Premolars**

*Uto-Aztecan premolar.* Upper premolars typically have two major cusps—one buccal and one lingual. For the second premolars, the main axes of the two cusps usually run in parallel. For first premolars, however, the distal margin of the buccal cusp often shows a buccalward rotation. Although this rotation is common, a more pronounced buccalward rotation of the distal margin with an associated fossa or pit is rare. Morris et al. (1978), who first described this trait in Papago Indians, believed it was limited to Uto-Aztecan speakers in the American Southwest. Although a few instances have since been found outside the Southwest, most cases have been observed in living or prehistoric Uto-Aztecan speakers (e.g., Pima, Hopi, or Papago). In Turner et al. (1991), this rare but interesting variant of UP1 is called the distosagittal ridge.

**Accessory ridges.** On the occlusal surface of the buccal cusp of the upper premolars, accessory ridges are often expressed on either side of the essential or median ridge. Distal accessory ridges are more common than mesial accessory ridges, and the second premolar has a higher frequency of ridges than the first premolar. These ridges vary in size, but the range of expression is too limited to divide this trait into any more than absent and two or three degrees of trait presence. Accessory ridges are sometimes evident on the lingual cusp, but these are far less common than ridges on the buccal cusp.

**Odontomes.** This accessory coronal tubercle can be expressed on the upper and lower premolars. Located in the central occlusal groove, between the buccal and the lingual cusps, this cone-shaped tubercle starts off as a pointed structure, but it does wear through time. Even though it seems to be primarily enamel, a worn odontome shows a dentine component.

St. Lawrence Island Eskimos have perhaps the highest frequencies of odontomes yet recorded. For the upper premolars, the incidence is 20.5% (18/88), whereas the lower premolar frequency is 14.1% (10/71) (Scott...
and Gillispie, 2002). Prehistoric Kodiak Islanders have frequencies of 2.2% (5/229) for upper premolars and 3.7% (9/242) for lower premolars (Scott, 1991). Based on these two series, it seems that upper or lower premolars are about equally likely to exhibit odontomes. In most world populations, this trait is rare.

**Upper premolar root number.** Upper premolars can express one, two, or three independent roots. This variation is, however, limited for the most part to the upper first premolar. UP1 should only be considered to have two roots when the inter-radicular projection extends from 1/4 to 1/3 of total root length (Turner, 1981). In the unusual case of three-rooted UP1, two roots are buccal and one is lingual, paralleling the pattern of UM1 roots.

**Maxillary Molars**

**Hypocone.** Early in primate evolutionary history, upper molars had three major cusps (protocone, paracone, and metacone) that made up the trigon. The hypocone was an additional cusp that originates from the distolingual cingulum (Gregory, 1922). In recent times, the hypocone has been treated as one of four major cusps of the upper molars, but it is, in fact, a late evolutionary addition that is in the process of being subtracted from the upper molars of modern humans (Fig. 9.9).

Dahlberg's classification of the hypocone included grades 3 (hypocone absent), 3+ (conule form), 4− (hypocone reduced), and 4 (hypocone normal in size). This scale was the foundation for a new classification that had absence and five degrees of trait presence (Larson, 1978). For this scale, grade 1 involved a hypocone outline but no free-standing cusp on the distolingual surface of the protocone. Grade 2, like Dahlberg's grade 3+, involved the presence of a small conule with a free apex. Grades 3 through 6 represented hypocones of increasing size although the use of UM1 and UN2 examples made the plaque difficult to use in some instances.

**Carabelli's trait.** This tuberculum projection is a cingular derivative on the mesiolingual cusp of the upper molars. It ranges in size from a slight deflected developmental groove to a large free-standing cusp that is almost the size of the hypocone (Fig. 9.10). The threshold expressions of this trait are subtle, so different observers may disagree on what constitutes absence or presence. In population studies, grade 3 is often used as a breakpoint to avoid this problem.

In upper molars, the typical wear gradient is buccal to lingual. When the protocone is worn down to 1/3 or more of total crown height, observations on Carabelli's trait are difficult to make. If this factor is not taken into account, the overall frequency of Carabelli's trait would be seriously underestimated.

**Cusp 5.** This accessory cusp is located on the distal marginal ridge of the upper molars between the metacone and the hypocone. Harris and Baillit (1980) refer to this variable as the metaconule. Once again, a large cusp 5 is very distinctive, but slight expressions of this trait are subtle, manifested as small vertical grooves extending down the distal surface of the molar. As with many supernumerary occlusal cusps, cusp 5 can wear down relatively quickly, making observations difficult in older adults.
Mesial marginal accessory tubercles. Three tubercles can develop along the mesial marginal ridge of the upper molars. These tubercles are associated, in turn, with the paracone (mesial paracone tubercle), the protocone (protocone tubercle), and the marginal ridge between the paracone and the protocone (mesial accessory tubercle) (Kanazawa et al., 1990, 1992). Although these tubercles can be distinct, they are often obscured by wear in early adulthood. Observations on children and adolescents yield the most reliable results for these marginal tubercles.

Enamel extensions. The cervical enamel line of the molars typically runs a straight or
horizontal course from the mesial to the distal margins of the upper molars. In some instances, however, the enamel line deflects toward the root in the area separating the mesial and distal roots. These extensions range from slight to pronounced deflections, with the latter sometimes terminating in an enamel pearl. This variable is manifest on both the buccal side of the upper and lower molars, although focus in population studies is usually on the upper molars (Turner et al., 1991).

**Upper molar root number.** The upper molars are anchored by three major roots (two buccal and one lingual). This ancestral condition has characterized primates for millions of years. This three-rooted condition is basically invariant on UM1, so this tooth fails to exhibit the type of variation that is useful for making population comparisons. However, UM2 is polymorphic, with one-, two-, or three-rooted teeth possible. Reduced root number is not accompanied by actual loss of root cones but rather by the fusion of two or more cones. To record root number, each distinct root should have an inter-radicular projection (bifurcation) at least 1/4 to 1/3 along the total length of the root complex.

**Mandibular Incisors**

**Shoveling.** Mesial and distal lingual marginal ridges are not limited to the upper incisors. They can also be expressed in the lower incisors but to a much lesser extent. Part of this is attributable to tooth size as the upper incisors are about 50% larger than the lower incisors. As shoveling expression shows a high correlation between the upper and the lower incisors (Scott, 1977a), UI1 is the key tooth for population studies.

Two other traits of the upper incisors—winging and *tuberculum dentale*—can be found in low frequencies, but because of rarity, researchers rarely score these traits on the lower incisors.

**Mandibular Canines**

**Distal accessory ridge.** Lower canines are incisiform and morphologically simplified. However, one relatively common discrete trait is expressed on the lingual surface between the median ridge and the distal marginal ridge. As it is found on the distal lobe segment, it is called a distal accessory ridge. Like the corresponding ridge on UC, this trait shows a significant sex difference (Kieser and Preston, 1981; Noss et al., 1983; Scott, 1977c). As crown wear often impacts the distal slope of the incisal edge first, this feature can wear off quickly in life.

**Root number.** Upper and lower incisors, along with upper canines, are one-rooted teeth. Of the anterior teeth, only the lower canine exhibits multiple roots in polymorphic frequencies.

To be scored as a two-rooted tooth, the bifurcation of the buccal and lingual root cones should occur in no less than 1/4 to 1/3 of total root length (Fig. 9.11). This trait is one of the few that is found most commonly in Europeans (Scott and Turner, 1997).

**Mandibular Premolars**

**Lingual cusp number.** Lower premolars invariably exhibit a single buccal cusp with a well-developed free apex. However, extensive variation occurs in the expression of the lingual cusp (or cusps). In contrast to the upper premolars, where the lingual cusp is centered effectively on the median ridge of the buccal cusp, lingual cusp expression on the lower premolars is far more asymmetrical and variable. Some lower first premolars, for example, have a lingual cusp fused to the buccal cusp that lacks a free apex. More commonly, the lingual cusp is well-developed and assumes a mesial position on the crown. If an extra lingual cusp occurs, it is usually situated on the ridge extending distally from the primary lingual cusp. This extra lingual cusp is typically smaller in overall size and lower on the occlusal plane than the primary lingual cusp. Although these principles apply to both LP1 and LP2, the extra lingual cusp is far more common on LP2 (Fig. 9.12).

Kraus and Furr (1953) describe 17 discrete variables for the lower first premolars, including
extra lingual cusps. Following their liberal definition of what constitutes a lingual cusp (any independent apex, no matter how slight), many lower premolars would be scored as "multiple lingual cusps" even though patterned variation in the size or position of lingual cusps is not taken into account. Ludwig (1957) defines seven traits, including multiple lingual cusps, for the lower second premolars. These workers have shown that useful untapped variation may occur in the lower premolar field that has not been exploited fully to date. For developing new trait classifications, the lower premolars are a good place to begin.

Accessory ridges. Like the upper premolars, the occlusal surfaces of the buccal cusp (protoconid) can exhibit either mesial or distal accessory ridges on the accessory lobe segments of the lower premolars. Mesial and distal ridges should be scored separately, even though they do exhibit some level of interaction. With their limited range of variation in size, absence and two or three grades of presence are considered adequate to score these ridges.

**Odontomes.** These coronal tubercles are described under maxillary premolars.

**Tomes’ root.** Although lower first premolars can exhibit two roots, the expression of the secondary root is different from upper first
premolars where distinct roots are associated with the two major cusps. The lower first premolar, by contrast, rarely exhibits a distinct bifurcation along a buccolingual plane. When two roots with slight-to-moderate separation are evident, this usually involves a division of the distobuccal and lingual root components. C.S. Tomes (1889) was the first to describe this root variant that bears his name.

**Mandibular Molars**

**Hypoconulid (cusp number).** Lower molars have five major cusps: 1) protoconid, 2) metaconid, 3) hypoconid, 4) entoconid, and 5) hypoconulid (Fig. 9.13). When there is variation in cusp number, it involves the hypoconulid or cusp 5. As with the hypocone, the hypoconulid was the last addition to the primate lower molar crown and is the first to be reduced in size or eliminated altogether. Although the hypoconulid varies in size, most workers report the frequency of four-cusped or five-cusped LM1 and LM2.

Early workers like William King Gregory (1922) reported cusp number sequence for the lower molars. Higher primates and early hominids retained the hypoconulid for the most part so they were characterized as 5–5–5. Over the course of hominid evolution, the fifth cusp was often lost, especially on the second molar. A cusp number sequence of 5–5–5, 5–4–5, or 5–4–4 would characterize most living populations.

**Groove pattern.** In the lower molars, the major cusps are separated by deep fissures or developmental grooves. The fissure pattern varies in a manner that impacts cusp contact at the central occlusal pit. In higher primates, the most common pattern involves contact between cusps 2 and 3. During hominid evolution, this pattern started changing, especially for LM2. In recent humans, it is common for cusps 1 and 4 to come in contact. Between these two patterns, there is a third and less common alternative where all four cusps come in contact at a single point. Groove pattern, defined by major cusp contact, is classified as Y (2–3 contact), X (1–4), and +(1–2–3–4) (Jørgensen, 1955).

Although no evidence supports a strong correlation between cusp number and groove
pattern, Gregory (1916) linked the two traits together in his famous *Dryopithecus* Y5 pattern. For Miocene hominoids, the description was accurate as most early apes had five major cusps and 2–3 cusp contact. In fact, most modern humans exhibit five cusps and a Y pattern on LM1. The noteworthy changes impact LM2 and to some extent LM3.

**Cusp 6.** The modal number of cusps in the lower molars is five. However, a relatively common supernumerary cusp is positioned between the entoconid (cusp 4) and the hypoconulid (cusp 5) referred to as cusp 6, or the *tuberculum sextum*. On the ASU plaque, which has grade 0 and five degrees of trait presence, C6 is judged relative to the size of C5. If C6 is small relative to C5, grade 1 is assigned. If it is about half the size of C5, then it is assigned to grade 2, which is by far the most common expression on the lower first molars. Grade 3 is used when C5 and C6 are equal, irrespective of absolute size. Grades 4 and 5 are reserved for those uncommon instances where C6 exceeds C5 in size.

One complaint leveled against the ASU classification focuses on the issue of whether the presence of C5 is required to have a C6. The hypoconulid (C5) is immediately distal to and closely associated with the hypoconid, hence the name hypoconulid. Cusp 6 is immediately distal to the entoconid and, correspondingly, is referred to as the entoconulid (Turner, 1970). Cusp 5, especially when large, can be centered perfectly between the hypoconid and the entoconid. More commonly, however, the hypoconulid lies more directly behind the hypoconid, with a position more buccal than lingual. What if the single distal cusp is situated behind the entoconid, so that position is more lingual than medial or buccal? When this occurs, some observers feel this signals the presence of cusp 6, even though there is only a single distal cusp. If this observation is valid, the effect on population studies would be relatively minor because it rarely applies to LM1, the key tooth for cusp 6 frequencies. However, there could be a secondary ramification for the LM2 cusp number. That is, workers could classify LM2 as five-cusped even though the fifth cusp may be C6 and not the hypoconulid, the defining distal cusp for the variable of cusp number.

**Cusp 7.** A second supernumerary cusp of the lower molars is cusp 7, or the *tuberculum intermedium*, situated between cusps 2 and 4. In the ASU classification, the plaque has absence (grade 0), grade 1A, and four grades of trait presence (1–4). Grade 1A has always been a problem as it is associated with the distal lobe segment of the metaconid—hence the name post-metaconulid. It is also the most common expression taken by cusp 7 on the deciduous lower second molar. Grine (1981) pointed out that some lower molars exhibit both a post-metaconulid and a wedge-shaped cusp 7. If they co-occur on the same tooth, they cannot be considered a single trait. For that reason, 1A expressions should be scored, but for population comparisons, workers should focus on the traditional wedge-shaped cusp 7 forms evidenced by grades 1 through 4 (Fig. 9.14).

**Protostylid.** This cingular derivative, often associated with the buccal groove between the protoconid and the hypoconid, is located on the mesiobuccal cusp of the lower molars (Dahlberg, 1950). In addition to positive cingular expressions, Dahlberg (1956) included buccal pits as grade 1 in his classification. Although the ASU standard follows Dahlberg's classification faithfully, including buccal pits as grade 1, no evidence supports the inclusion of negative pits with positive cingular expressions. Although buccal pits should be scored, their use in estimating population frequencies of the protostylid is questionable.

**Deflecting wrinkle.** The essential ridge of the metaconid usually runs a straight course from the cusp tip to the central occlusal pit. However, in some cases, this ridge begins with a more mesial orientation before changing course toward the center of the tooth, hence,
Figure 9.14 Cusp 7 is located between the metaconid and the entoconid of the lower molars. At one time, it was thought that the post-metaconulid was a manifestation of cusp 7, but the post-metaconulid and cusp 7 can both be expressed on the same tooth. In (b), the lower first molar exhibits a moderate cusp 7, whereas the lower second premolar exhibits a rare odontome.

the same deflecting wrinkle. Although the ASU standard includes grade 0 and three degrees of grade presence (Turner et al., 1991), most workers focus on grade 3 expressions. The key tooth for deflecting wrinkle observations is LM1. It is unusual to find this trait on LM2 or LM3.

Root number (LM1). The modal root number for lower molars is two, with one mesial and one distal root. Root grooves are often present on either root producing three or four radicals. World populations almost always adhere to this modal root number, but there is a supernumerary root that can develop on the lingual border of the distal root, hence, the name distolingual root. As this extra root makes the tooth three-rooted, the trait is often referred to in shorthand form as 3RM1 (three-rooted lower first molar). This extra root, which is most common in North Asians and Eskimo-Aleuts, is rare on LM2 and LM3.

Root number (LM2). Rather than exhibiting extra roots, LM2 often shows a reduction in root number. There are three ways that a two-rooted lower molar’s roots can fuse to produce a single-rooted tooth. The root cones may fuse along the buccal axis, along the lingual axis, or both. When root fusion precludes the expression of independent roots for at least 1/4 to 1/3 of total root length, the tooth is classified as single rooted.

Observational Methods
Once a trait set has been chosen for a population study, the worker has to decide how to best observe each trait. With the exception of shoveling, where some workers have had success
measuring the depth of the lingual fossa (Aas, 1979; Aas and Risnes 1979a, 1979b; Blanco and Chakraborty, 1977; Dahlberg and Mikkelsen, 1947). It has been difficult to measure teeth on an interval scale (but see Taverne et al., 1979). For most variables, no landmarks are consistently present because of a combination of size and shape considerations, not to mention complications introduced by crown wear, casting error, or tooth breakage.

Hanihara et al. (1970) quantified the size of the hypocone through the use of photographs, but this method is time consuming, expensive, and does not address shape concerns, especially for low grades of expression. The method works well for UM1, which consistently expresses a hypocone but is less useful for the more variable UM2 and UM3, where the hypocone is often reduced or lost altogether. Of course, this method requires teeth that show very little wear. Because of these limitations, no workers have adopted this method for scoring variation in hypocone size.

Because most dental traits are either present or absent and exhibit variable degrees of expression when present, there are different ways to characterize a population for a particular trait. At the most basic level, traits can be dichotomized as present (+) or absent (−). This approach is popular among researchers who focus on nonmetric cranial traits. However, the dividing line between present and absent is always “fuzzy.” Berry (1976:259) notes “the dubious presence of a variant was scored as 0.50 provided that the scoring difficulty was due to a genuine minimal expression of a variant rather than to attrition.” During my dissertation research, I noted questionable expressions that fell on or close to the threshold by the letter L (Scott, 1973). Anyone who has scored crown and root traits has faced this conundrum—to be or not to be,” that is the question.

Because of the difficulties introduced by threshold expressions, Turner (1985a, 1986a; Turner et al., 1991) adopted the strategy of using breakpoints on ranked scales to dichotomize groups. This was not applied to all traits but primarily to those where the line between presence and absence was blurred (e.g., shoveling or Carabelli’s trait). If reference is made to a specific expression on a standard plaque and you use this point as a basis for sample frequencies, this increases the comparability of datasets collected by different workers. Of course, whenever possible, numbers and frequencies for all grades of expression should be reported.

Although the use of standardized ranked scales is recommended strongly, the use of all ranks in population comparisons is usually unnecessary. Turner (1985a) developed an expression count method for dental traits that was aimed at calculating frequencies based on weighted ranks. Although this method uses data on expressivity more thoroughly, it was never adopted by other workers in the field nor used by Turner in later population analyses. In the context of genetic analysis, I used a value called MSA or the “mean score of affected” individuals (Scott, 1973). However, distance statistics typically are designed to analyze frequencies or sample means, so I did not use the MSA in population comparisons. Although some quantitative method to take all ranks into account might provide information above and beyond total trait frequency, it should be emphasized that quasiconfidential traits are best characterized by a single frequency as this specifies the nature of the entire normal distribution (Falconer, 1960).

Asymmetry and Counting Methods

Although the dentition is characterized by mirror imagery between the two sides of the jaw, teeth on opposite sides of the jaw—antimeres—can exhibit asymmetry in size, morphology, and hypodontia (congenitally missing teeth, especially M3). Many workers have shown this asymmetry shows no side preference so it is referred to as fluctuating asymmetry rather than as directional asymmetry (Mizoguchi, 1988; Saunders and Mayhall, 1982; Scott, 1980; Van Valen, 1962).
Given the lack of directional bias in trait expression, there are three methods for scoring and tabulating crown and root trait frequencies:

- Side count: With this method, followed often by those who measure teeth but occasionally by those who observe morphology, a worker scores only left or right antimeres for trait expression. The caveat is often stated that only one side will be scored, but if the antimeres on that side is missing, the tooth from the other side can be used. This method is the most efficient in terms of scoring and tabulation because the issue of asymmetry is removed from the process.

- Tooth count: With a large collection of loose teeth, this is the only method that can be followed when antimeres cannot be matched. Basically, all teeth, both left and right, are scored for the expression of a trait. When the data are tabulated, the population frequency is based on all teeth scored, whether they are antimeres or not. Some workers use this method for deriving trait frequencies even when studying whole dentitions (casts or skulls).

- Individual count: This method combines elements of the side and tooth count methods and provides a rationale for dealing with the issue of asymmetry. For deriving frequencies based on individual counts, all teeth are scored for crown and root traits. However, when individuals are scored for a trait on both antimeres, only the antimeres with the highest grade of trait expression is used to characterize that individual. The rationale for this procedure is that an individual has only a single genotype directing dental development. If two antimeres exhibit grades 1 and 4 phenotypes, which of the two best reflects the underlying genotype of that individual? Adherents of this method contend it is the more pronounced phenotype that best reflects the underlying genotype. The hypothetical case above would be scored at 4 in the final tabulation (not 1, not 2.5, and not 1 and 4, the three other alternatives) (Turner and Scott, 1977; Turner et al., 1991).

Although the debate over appropriate counting methods has been contentious at times, so little asymmetry exists in dental morphology that any method can be used to arrive at similar results (cf. Scott, 1980). The only method that has a major weakness is the tooth count method. Given the high degree of symmetry in nonmetric dental traits, a tooth count artificially increases sample size with very little new information. As sample size is a critical element of estimating sample variance and testing hypotheses, this method should not be followed except in the case of loose teeth where there is no other choice. In the ASU system, the individual count method is preferred although results differ little from those obtained by a side count.

**Intraobserver and Interobserver Error**

It is a straightforward matter to teach students how to observe a distinct example of shoveling, Carabelli’s trait, cusp 7, or any other crown or root trait. However, to make consistent observations on ranked scales and to distinguish the subtle expressions that separate absence from presence, research on dental morphology requires experience and caution. In the literature several egregious examples of observations are so far off base that they are impossible. The reasons for such observational error may be from inexperience, the lack of adequate operational definitions, bad lighting, poor magnification, hurried observations, or some combination thereof.

Although researchers rarely address such things, there is an element of “art” in the study of dental morphology. I do not mean the study of such traits is not scientific—it is simply an acknowledgment that some experience is required to make hundred or thousands of individual decisions on “present or absent”
and “grade of expression when present.” Before setting off on any dental morphological research, it would behoove any worker to observe a sample of casts or skeletons for a particular set of traits. Then, after a month or more, return to the same sample and repeat your observations. This assessment of intraobserver error provides a benchmark for your research. You will find that some observations can be replicated at a very high level (>90%), whereas other variables pose problems in consistent scoring (Nichol and Turner, 1986; Scott, 1973). At that point, you either want to hone your skills on traits that cause the most problems or eliminate them from your trait list.

After gaining experience and testing your ability to replicate observations, you are ready to begin your study. However, the issue of error is not entirely behind you. When you tabulate your data and evaluate your trait frequencies, you should also assess your results in the context of comparisons with other observers. If you find a total shoveling frequency of 50% in American Indians, you should evaluate your breakpoint as most workers have found this frequency to be 90–100%. If you find a cusp 7 frequency of 80% in a Native American sample, you should reflect on your scoring methods as this trait is less than 10% in most populations and only 40–50% in Africans who have by far the highest prevalence of this trait in the world (Scott and Turner, 1997).

**POPULATION STUDIES**

**Defining a Problem**


When workers make observations on dental morphology, this is usually in the context of a problem or set of problems. However, some morphological studies are descriptive in nature. To observe, tabulate, and report the frequency of a trait in a population is not a problem-oriented approach, even though such descriptive studies are useful when others assess the data in a broader population analysis. Although most dental morphological analyses focus on between-group comparisons, some within-group analysis is possible. For example, if you had a sample from one population, several issues could be addressed: 1) sex differences—do males and females show significant differences in the frequency and expression of a morphological trait? 2) fluctuating asymmetry—do different morphological variables show the same levels of asymmetry or are some traits more asymmetric than others? and 3) trait interaction—do different morphological traits in the same and different fields show significant correlations or are they expressed independently of one another? Should crown dimensions be measured along with morphological traits, one can address whether these traits are expressed independently of tooth size. If your sample is composed of families or twins, you can address genetic issues through intrafamilial correlations and
CONCORDANCE–DISCORDANCE RATES IN MZ AND DZ TWINS, EITHER OF WHICH CAN BE USED TO ESTIMATE HERITABILITY. THE POINT IS THAT YOU CAN ADDRESS SOME PROBLEMS IF YOU ONLY HAVE A SINGLE POPULATION SAMPLE AT YOUR DISPOSAL. HOWEVER, IF YOU OBSERVE MULTIPLE SAMPLES, YOU CAN EMPLOY METHODS OF COMPARATIVE ANALYSIS AND ADDRESS A WIDER RANGE OF PROBLEMS.


ALTHOUGH MOST RECENT STUDIES FOCUS ON POPULATION RELATIONSHIPS, TWO AREAS WHERE DENTAL MORPHOLOGY HAS GREAT BUT UNTAPPED PROMISE ARE 1) ADMIXTURE ANALYSIS AND 2) ETHNIC IDENTIFICATION IN FORENSIC CONTEXTS. EDGAR (2002) HAS DEMONSTRATED THIS PROMISE IN HER RESEARCH ON EUROPEAN, AFRICAN, AND AFRICAN–AMERICAN DENTITIONS. ADMIXED GROUPS SHOW INTERMEDIATE CROWN AND ROOT TRAIT FREQUENCIES, BUT THE PRECISION WITH WHICH WE CAN USE THESE TRAITS REQUIRES MORE RESEARCH. IN HIS TEXTBOOK ON FORENSIC ANTHROPOLOGY, BYERS (2001) HAS ONE SMALL TABLE ILLUSTRATING HOW A FEW DENTAL TRAITS DIFFER AMONG EUROPEANS, AFRICANS, AND ASIANS. IT REPRESENTS ONLY THE TIP OF THE ICEBERG ON HOW MORPHOLOGY COULD BE USED TO IDENTIFY INDIVIDUAL ETHNIC AFFILIATION IN A FORENSIC CONTEXT.

LIVING OR DEAD?

THE FIRST 10 YEARS OF MY CAREER INVOLVED THE ANALYSIS OF THOUSANDS OF DENTAL CASTS FROM SOUTHWEST INDIAN TRIBES AND AMERICAN WHITE
family and twin samples (cf. Scott, 1973; Scott and Dahlberg, 1982; Scott and Potter, 1984; Scott et al., 1983, 1988). Over the past 20 years, my focus has shifted almost entirely to skeletal collections from the American Arctic and North Atlantic (cf. Scott, 1991, 1992; Scott and Alexandersen, 1992; Scott and Gillispie, 2002; Scott et al., 1992) and, more recently, from Spain. I have also taken advantage of the special quality of teeth and compared the dentitions of extinct and extant Kodiak Islanders (Scott, 1994). With this experience, I have gained several insights into the advantages and disadvantages of studying casts and skulls.

**Casts**

*Advantages.* As casts are obtained from living populations, you can establish your own agenda in terms of sample size and age profile. Because of fillings, wear, and tooth loss, many workers who collect impressions focus on children and teenagers whose crown morphology is least impacted by the ravages of time and disease. If you have the resources and a population’s approval, you can obtain thousands of impressions like Al and Thelma Dahlberg did among the Pima Indians. With less time and more limited resources, it is still feasible to collect one or two hundred impressions, which is a large enough sample to provide a good population characterization.

*Disadvantages.* Until I studied Basque and Spanish casts in the summer of 2005, I had forgotten one major disadvantage of casts—you can only observe crown traits. Moreover, although conditions vary between populations, casts from living populations pose significant problems for scoring some traits. This problem is especially true for groove pattern and other variables located primarily on the occlusal surfaces of the premolars and molars. In recent populations, caries has been rampant, so a significant fraction of a sample is lost because fillings obscure a trait’s locus. Finally, if you have only casts, that means you have no temporal variation to speak of, so problems of microevolution cannot be addressed.

**Skulls**

*Advantages.* A big advantage in studying skeletal remains is the inclusion of root traits in your morphological protocol. Root variants can even be observed when a tooth is absent. Equally important is the ability to study skeletal series distributed through time, which makes it possible to evaluate microevolutionary changes in the dentition.

*Disadvantages.* Downsides exist to the study of skeletons. For example, a paleodemographic fact of life is that once individuals survive infancy, they usually live until middle-to-late adulthood. Any given skeletal collection has a relatively small percentage of children and teenagers, exactly those individuals whose teeth are least impacted by disease and wear. Dental attrition is a major limiting factor in the study of skeletons because earlier human populations wore down their teeth at a much faster rate than modern populations. Even in relatively young individuals (late teens, early 20s), when the protocone is worn, precise observations on Carabelli’s trait are difficult to make. In addition to wear, postmortem tooth loss also acts to reduce sample size. As the single-rooted anterior teeth are especially subject to postmortem loss, the ultimate sample size for traits such as shoveling and *tuberculum dentale* are reduced greatly. The multirooted molars, especially root traits, typically have the largest sample sizes. Thus, it should be borne in mind that 100 skeletons will not provide a sample of 100 for the traits you are observing.

To illustrate sampling limitation of skeletal remains, observations on 155 St. Lawrence Island Eskimo skeletons yielded the following sample sizes for a standard set of traits: U11 shoveling (29), U11 *tuberculum dentale* (34), UC distal accessory ridge (34), UP1 odontomes (51), UM2 hypocone (70), UM1 Carabelli’s trait (54), UM1 cusp 5 (34), LP1 multiple
lingual cusps (54), LM1 deflecting wrinkle (46), LM2 hypoconulid (70), LM2 groove pattern (93), LM1 cusp 6 (43), LM1 cusp 7 (81), and three-rooted LM1 (59) (Scott and Gillespie, 2002). These numbers indicate that traits on the anterior teeth can be scored in about 20% of the total skeletal sample. Premolar traits are somewhat better, yielding samples sizes of about 30%. The multirooted molars yield the biggest samples, but even here only 35–60% of the teeth from the total sample are scorable. The variation in frequencies between traits indicates they are impacted variably by crown wear, tooth loss, and other environmental effects. By way of contrast, in a sample of 1528 Pima Indian casts, about 80% of the total sample could be observed for U1 shoveling, UM1 Carabelli’s trait, UM1 hypocone, LM1 cusp number, and LM1 cusp 6. The only trait on LM1 that was relatively limited was groove pattern at 50%, supporting the earlier point on the effect of fillings on the occlusal surfaces of living populations.

A final point in the cast–skull debate is whether it is easier to score subtle shades of morphology on casts or on real teeth. For either, the use of a good light and a 10× magnifying lens are highly recommended. Given the same observational conditions, it is hard to say either has a major advantage. Casting error can be an issue as air bubbles can obscure the site where a trait is scored. Untreated casts present a very dull appearance, so many dentists rub them with baby powder to develop sheen for enhanced contrast. Personally; I find it easier to make observations on casts treated with baby powder, but this may be a matter of taste. Although real teeth have no issues of casting error, the enamel does reflect light making subtle expressions difficult to observe. One has to be careful to examine the trait’s locus under good light from all possible angles or subtle trait expressions can be overlooked easily.

One method for studying crown morphology that I do not recommend is intraoral observations in living individuals. Not only do real teeth reflect light, but the reflectance is exacerbated by the presence of saliva. Although large expressions of traits are observed easily in vivo, any slight manifestations are hard to score because of light issues and the limited number of views available during such examinations. Fortunately, most anthropologists appreciate the limitations of intraoral observations, so this is not a major problem in dental morphological studies.

**Permanent or Deciduous?**

Over 90% of the papers published on human dental morphology focus on the permanent dentition. Some researchers, in particular Kazuo Hanaihara (1956, 1960, 1963, 1966) and Paul Sciulli (1977, 1990, 1998), plus a few others (Grine, 1986, 1990; Jørgensen, 1956; Lukacs and Walimbe, 1984), have devoted time to the analysis of deciduous morphology, but they are exceptions to the rule.

In an early influential review of the field, Lasker (1950) actively discouraged the study of deciduous dental morphology. He argued that the traits observable on primary teeth are the same as those evident on permanent teeth, so few new insights could be gained from the study of deciduous morphology. Although Lasker was correct to note the overlap between primary and permanent crown and root morphology, deciduous teeth do offer another perspective on morphological variation.

Deciduous teeth, as the developmental precursors of the permanent teeth, presage morphological characteristics that are exhibited in the permanent dentition. For example, children from Asian and Asian-derived populations often show shovel-shaped primary incisors, even though the teeth are smaller and trait development never reaches the same level. Traits exhibited on dm2 also foreshadow the expression of variables in the permanent molar field (Fig. 9.15). It is common to see Carabelli’s cusp, the hypocone, cusp 5, and other features of the permanent upper molars on dm2. The same is true for groove pattern, cusp 6, cusp 7, the protostylid, deflecting wrinkle, and distal trigonid crest on the lower molars. Dahlberg (1945) and others often
considered dm1 the first member of the molar field.

The most unusual teeth in the primary dentition are the upper and lower first molars. The upper first molar is typically a two-cusped tooth (one buccal and one lingual) that shows a general similarity to upper premolars, albeit somewhat wider in the BL dimension. The lower first primary molar is the most unusual baby tooth. It is elongated in an anteroposterior direction and shows some similarities to the sectorial third premolar of monkeys and apes. Although these teeth are also succeeded by lower premolars, they do not look like the premolars of modern humans.

Although Lasker’s comments may have discouraged a few workers from considering deciduous tooth morphology, a more important limiting factor is sample size. Most researchers, who collect casts, prefer individuals with all their permanent teeth (except for M3). Thus, they typically focus on school-aged children around the age of 10 years or older. Some deciduous teeth are present in such a sample, but numbers are limited. As noted, there are relatively few children in archaeological assemblages, so this limits the availability of primary teeth in this context.

If a researcher wants to address issues with deciduous dental morphology, and there is a niche out there for new students, they have to collect impressions from preschoolers or kindergarten-aged children. This avoids a mixed dentition and enhances sample size for teeth that are lost early (mostly the incisors). The second alternative is to examine primary teeth in skeletons, but this does require a large skeletal collection with very good preservation to provide enough cases to make up a statistically valid sample.

How Many Traits?

In 1950, W.C. Boyd used three blood group systems (ABO, Rh, and MN) to assess worldwide genetic variation. Four decades later, Cavalli-Sforza et al. (1994) analyzed 120 alleles to delineate regional and global genetic differentiation. Livingstone (1991) would argue that the expanded analysis is more reliable and urges researchers to use as many variables as possible in the evaluation of population relationships.

Early dental researchers usually focused on a limited number of dental variables—primarily shovel-shaped incisors, upper molar cusp number, Carabelli’s trait, and lower molar cusp number and groove pattern. Some augmented this battery with a few additional traits such as incisor winging and lower molar cusp 6,
cusp 7, the protostylid, distal trigonid crest, and deflecting wrinkle. If only a single tooth is used to represent each trait, the number of "classic" variables falls between five and ten.

K. and T. Hanhara have traditionally used six to nine morphological variables in their population studies, with their entire focus on crown traits (cf. K. Hanhara, 1968; T. Hanhara, 1992b). A recent study by Matsumura and Hudson (2005) on Asian dental variation employed 16 traits following some parts of the ASUDAS, but they included only one root trait (UP1 root number). In a study of East Asian dentitions, Turner (1987) observed 28 dental variables, including six root traits. In an analysis of ancient Egyptians, Irish (2006) used 31 dental variables, not counting palatine and mandibular tori and rocker jaw. When I had to address whether the early period inhabitants of Kodiak Island (Kachemak) differed in any significant way from later period peoples (Koniag), I used 22 dental variables, of which 16 were crown traits and 6 were root traits (Scott, 1991, 1992).

If your observations focus on dental casts, I would consider the following list of traits a minimal set (key tooth also noted):

1. Bilateral winging (UI1)
2. Shovel-shaped incisors (UI1)
3. Double-shoveling (UI1)
4. Interruption grooves (UI2)
5. Tuberculum dentale (UI1 or UC)
6. Carabelli's trait (UM1)
7. Hypocone (UM2)
8. Cusp 5 or metaconule (UM1)
9. Distal accessory ridge (LC)
10. Multiple lingual cusps (LP2)
11. Cusp number/hypocoenulid (LM1, LM2)
12. Groove pattern (LM2)
13. Cusp 6 (LM1)
14. Cusp 7 (LM1)
15. Protostylid (LM1)
16. Deflecting wrinkle (LM1)

If skeletal remains are analyzed, the following crown and root traits should be added to the list above:

1. Enamel extensions (UM1)
2. UP1 root number
3. UM2 root number
4. LC root number
5. Tomes' root (LP1)
6. LM1 root number (3RM1)
7. LM2 root number

Depending on geographic region, a researcher might add one or more of the following traits to their protocol:

1. Labial convexity (UI1)
2. Premolar odontomes (North Asia, American Arctic) (UP1, UP2, LP1, LP2)
3. Uto-Aztecan premolar (North and South America) (UP1)
4. Bushmen canine (Africa) (UC)
5. Distal trigonid crest (LM1)
6. Marginal tubercles (UP1, UP2)
7. Mesial and distal accessory ridges (UP1, UP2, LP1, LP2)
8. Protoconule, mesial accessory tubercle, mesial paracone tubercle (UM1)
9. Anterior fovea (LM1)

Concluding Thoughts

Hopefully, I have provided some direction and guidelines for future students of human dental morphology. There are a plethora of interesting historical and processual issues to address using crown and root variation. I strongly encourage students to evaluate the current status of morphological studies and to think of ways to push them forward. The development of new trait classifications would be one place to start. The ASUDAS is a foundation, like the Dahlberg system was an earlier foundation, but it should not be considered a finished project. Like a large medieval cathedral, it is a
work in progress. To complement methodologi-
cal advancements, new types of problems
should be addressed. As noted, the use of
tooth morphology in admixture studies and the
ethnic identification of forensic remains are
fertile grounds for expansion. Evaluating
the possible action of natural selection on mor-
phology is another research avenue to pursue.
Already, many scholars are beginning to look
at the same morphological features in fossil
hominids that we examine in living and recent
skeletal populations. Delineating long-term
evolutionary trends and assessing how diet,
behavior, and climate impacts crown and root
morphology are on the horizon. The future
study of dental morphology is bright, so for all
of you contemplating research in this area, to
misquote a famous Vulcan, “go forth and
prosper.”

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