Identifying and Recording Key Morphological (Nonmetric) Crown and Root Traits

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In biology, morphology refers to structure and form. For teeth, morphology means different things to dentists and dental anthropologists. Carlsen (1987) wrote a book called *Dental Morphology* that focused on the structure of the four types of teeth in the upper and lower jaws. Each tooth was broken down into its constituent parts, such as lobes, lobe segments, essential and accessory ridges, cusps, tubercles, and so forth. The book was aimed primarily at basic dental anatomy classes as taught in dental schools. For dentists, it is the standard form of an upper central incisor that is important in clinical practice. Variation around the “type” of each tooth is minimally relevant when the goal is drilling and filling.

For the dental anthropologist, the typical form of a tooth is interesting, but more important is variation around the type. An upper first molar, for example, typically has four cusps and three roots. The three major cusps are arranged in a triangle (trigon), while the fourth cusp is a late evolutionary addition on the distolingual aspect of the major lingual cusp (protocone). This fourth cusp is referred to as the hypocone (see Chapters 3 and 7). On modern human teeth, the hypocone is present on the upper first molar around 99% of the time, being so common that it is almost invariant. The presence of the hypocone on the second and third molars is another matter. Some populations retain the second molar hypocone in high frequencies, but others show significantly lower frequencies. The presence or absence of the hypocone is the primary determinant of upper molar cusp number, one of the earliest morphological traits used by anthropologists to compare geographically dispersed human populations (Gregory 1922).
The aim of this chapter is to describe the crown and root traits that anthropologists and other dental researchers employ in population studies. In addition, issues that must be taken into account when making morphological observations include: counting methods; the impact of wear and pathology; the issue of threshold expressions; key traits and inter-trait correlations; observations on casts vs. skeletons; and intra- and inter-observer error (Scott 2008). The following crown and root traits fall within the Arizona State University Dental Anthropology System (Turner, Nichol, and Scott 1991), but the ranked scales associated with many traits are not described. The reader should consult other publications that illustrate or describe these scales (Hillson 1996; Turner, Nichol, and Scott 1991).

**Crown Traits**

The term cusp refers to distinct, elevated features on a tooth crown. With the exception of incisors (with an incisal edge), each human tooth has one or more major cusps: canines (1 cusp), premolars (2 or more), upper molars (3 or 4), and lower molars (4 or 5). Carlsen (1987) uses lobe rather than cusp to describe crown macromorphology. Although the terms appear interchangeable, there are advantages to using lobes when describing subunits of a cusp (or lobe). For example, take the buccal cusp of an upper premolar. The cusp (lobe) is made up of three lobe segments; the essential lobe occupies a central position and is flanked by two accessory lobe segments, one mesial and one distal. The same characterization applies to major cusps of the upper and lower molars. While these lobe segments are invariant components of all human teeth, other elements of these segments can be present or absent; that is, discrete variation. For example, on the buccal cusps of premolars, the occlusal surface of the mesial and distal accessory lobe segments may or may not exhibit ridges. Because of their location, these variable traits are referred to as mesial and distal accessory ridges. Nonmetric tooth crown traits take a variety of forms. Four macromorphological units defined by Carlsen (1987) are: marginal ridge complex; cingulum derivative; supernumerary coronal structure; and cervical enamel line. Major variants that do not fall under these headings include major cusp number and supernumerary cusps. These six categories are used to outline the major nonmetric crown traits to follow. Additional traits that do not fall clearly within one of these six categories are described under miscellany.

**Marginal Ridge Complex**

- **Shoveling**: mesial and distal lingual marginal ridges on the anterior teeth, with more pronounced forms enclosing a fossa (Hrdlička 1920). The greatest variation in shoveling is shown by the upper central and lateral incisors with UI1 the key (or polar) tooth (Figure 17.1a).
- **Double-shoveling**: mesial and distal labial marginal ridges on the anterior teeth, with the mesial ridge typically the most pronounced. The key tooth is UI1 (Figure 17.1a).
- **Canine mesial ridge (Bushman canine)**: it is a combination of the mesial marginal ridge of the upper canine in concert with a cingulum projection, or tuberculum dentale, on the basal eminence (Figure 17.1b). The key tooth is UC.
identifying and recording key morphological (nonmetric) crown traits. (a) Vertical arrows point at mesial and distal marginal ridges, the defining characteristic of shovel-shaped incisors; note barrel-shaped UI2, the most pronounced form of shoveling for this tooth. Another arrow points to mesial marginal ridge on labial surface of UI1, the diagnostic feature of double shoveling (CGT). (b) Arrow points to mesial canine ridge, or Bushman canine; antimer shows a tuberculum dentale not incorporated into mesial marginal ridge (GRS). (c) Uto-Aztecan premolar; note strong buccalward displacement of distal margin of buccal cusp; along distal margin is a fovea (CGT). (d) Arrows point to tuberculum dentale on all upper anterior teeth; this cingular trait often takes the form of ridges on UI1 and UI2, while UC exhibits pronounced tubercle. Note symmetry in trait expression between antimeres (CGT). (e) Arrows point to Carabelli’s trait on mesiolingual cusp of dm2 and UM1; this cingular trait ranges from small groove to large free-standing cusp (GRS). (f) Protostylid is expressed as positive form on mesiobuccal cusp of all three lower molars; this cingular trait shows some association with Carabelli’s trait, its counterpart in upper molars (CGT).
Distosagittal ridge (Uto-Aztecan premolar): this rare variant of the UP1 involves a pronounced buccal rotation of the distal aspect of the buccal cusp, typically resulting in a pit or fossa along the distal marginal ridge. This trait has only been observed on UP1 (Figure 17.1c).

Premolar mesial and distal accessory cusps (tubercles): these accessory tubercles can be found on either the mesial and/or distal margins of the sagittal groove of upper premolars; to be scored as a tubercle, they must exhibit grooves that clearly separate them from the buccal and lingual cusps. The key tooth is UP1.

Cingulum Derivatives

- Tuberculum dentale: expressed on the lingual aspect of the basal eminence of the upper anterior teeth, this trait takes a number of forms, but is most often expressed as ridges and tubercles. On the lateral incisor, this trait is highly variable and can be expressed as ridges, tubercles, or a shelf. On the upper canine, the trait is usually singular and ranges from a small ridge to a large free-standing tubercle. The key tooth is either UI1 or UC (Figure 17.1d).

- Carabelli’s trait: this feature is manifest on the lingual surface of the mesiolingual cusp (protocone) of the upper molars. It is highly variable, ranging from a small groove or pit through a number of intermediate grades up to a large free-standing tubercle (Scott 1980). The key tooth is UM1 (Figure 17.1e).

- Protostylid: this trait is expressed on the buccal surface of the mesiobuccal cusp of the lower molars. Dahlberg (1956) classified a buccal pit between the protoconid (cusp 1) and hypoconid (cusp 4) as grade 1 and this was adopted by ASUDAS (Turner, Nichol, and Scott 1991). Grades 2–7 represent increasingly large positive manifestations of this cingular trait. The key tooth is LM1 (Figure 17.1f).

Supernumerary Coronal Structures

- Odontomes (tuberculated premolars): projections, often conical in shape, are centrally located in the sagittal groove of upper and lower premolars. There is often a dentine component to this trait, as evidenced following occlusal wear or breakage. At this time, there is no key tooth for odontomes, so frequencies are based on all upper and lower premolars (Figure 17.2a).

Cervical Enamel Line

- Enamel extensions: the crown–root junction on the buccal surface of the upper and lower molars is usually horizontal, but in some instances the enamel extends away from the crown toward the root. This extension ranges from a slight deflection to a pronounced extension, sometimes accompanied by an enamel pearl. The key tooth is UM1, but could be LM1 as well (Figure 17.2b).

Variation in Major Cusps

- Hypocone: the standard upper molar has four cusps: the protocone (cusp 1), paracone (2), metacone (3), and hypocone (cusp 4). Before ranked scales were developed, the trait “upper molar cusp number” was scored as either 4 or 3. A 3-cusped tooth lacks the distolingual cusp, or hypocone. The hypocone ranges in expression from complete
Figure 17.2  Morphological crown traits. (a) Conical odontome noted by arrow; wear shows dentine component to odontome (CGT). (b) LM1 and LM2 exhibit enamel extensions that project between buccal surfaces of roots; this trait can also be expressed by upper molars (CGT). (c) Upper molars often exhibit four major cusps as shown by UM1; cusp number 4, hypocone, is distinct on UM1 but missing on UM2, producing 3-cusped upper molar (GRS). (d) Lower molars often exhibit five cusps, but here both LM1 and LM2 fail to express hypoconulid, producing 4-cusped lower molars. Arrow points to location where hypoconulid would be expressed, if present (CGT). (e) Rare tricusped UP1 with one buccal cusp and two distinct lingual cusps (CGT). (f) Cusp 5 expressed as small tubercle between hypocone and metacone of upper molars; arrow points to C5 on UM2 (GRS).
absence through several intermediate expressions up to a large cusp comparable in size to other major cusps. Since the hypocone is almost invariably present on UM1, studies that focus on variation use UM2 as the key tooth (Figure 17.2c).

- **Metacone**: after the hypocone, the other major cusp of the upper molars that can show size reduction is the metacone. Although it can be reduced in size, it is rarely absent. The key tooth is UM2.

- **Hypoconulid**: the standard lower molar has five cusps: the protoconid (cusp 1), the metaconid (cusp 2), the hypoconid (cusp 3), the entoconid (cusp 4), and the hypoconulid (cusp 5). Prior to ranked scales, the lower molar cusp number was scored as 5 or 4. A 4-cusped tooth lacked the distal cusp, or hypoconulid. Although the hypoconulid varies from absence through intermediate expressions to a pronounced cusp, the importance of this variable is measured by individuals lacking the hypoconulid, thus expressing 4-cusped teeth. UM1 and UM2 should both be scored for hypoconulid expression (Figure 17.2d).

**Supernumerary Cusps**

- **Tricusped premolars**: upper premolars are often referred to as “bicuspids” because 99.9% of the time they exhibit one buccal cusp and one lingual cusp. On rare occasions, the lingual cusp is bifurcated, the result of which is a tricuspid upper premolar. The key tooth for this extremely rare trait is UP1 (Figure 17.2e).

- **Cusp 5 (metaconule)**: this trait is part of the marginal ridge complex, but is more often listed as a supernumerary cusp. It is expressed as a small cusp or tubercle between the metacone and hypocone of the upper molars. There should be two vertical grooves on the distal surface of the tooth associated with a small projection. The key tooth is UM1 (Figure 17.2f).

- **Lower premolar multiple lingual cusps**: in contrast to the upper premolars, which almost invariably have one buccal cusp and one lingual cusp, the lower premolars show extensive variation in the form of the lingual cusp(s). On LP1, the lingual cusp may not even have a free apex, so the lingual cusp number is scored as zero. In other instances, there may be one major lingual cusp (often mesial of center), or one or more small lingual cuspules (Figure 17.3a). LP2 is more molariform than LP1 and usually exhibits one or more lingual cusps. Although there is a ranked scale with eight grades of expression, observers often reduce this variable to the presence of two or more lingual cusps. LP2 is the key tooth for lingual cusp number.

- **Cusp 6**: another name for this trait is *tuberculum sextum*. As a derivative of the entoconid, Turner (1970) also referred to it as the entoconulid. This supernumerary cusp is manifest between the hypoconulid and the entoconid. It is typically much smaller than the hypoconulid, but it can, on occasion, equal or exceed the size of the hypoconulid. The key tooth is LM1 (Figure 17.3b).

- **Cusp 7**: because of its location between the metaconid and entoconid, this supernumerary cusp was referred to as *tuberculum intermedium*. Because of its association with the metaconid, Turner (1970) also used the term metaconulid. Since the metaconulid is derived from the distal lobe segment of the metaconid and can be expressed at the same time as cusp 7, it is preferable to retain the numerical designation for this trait. On the cusp 7 plaque (Turner, Nichol, and Scott 1991), grade 1A is technically the metaconulid and should not be used in tabulating cusp 7 frequencies. The key tooth is LM1 (Figure 17.3c).
Figure 17.3 Morphological crown traits. (a) In this mandible there are three right premolars. LP1 exhibits single lingual cusp while LP2 and supernumerary premolar exhibit multiple lingual cusps (GRS). (b) LM1 exhibiting deflecting wrinkle (top arrow) and cusp 6 (bottom arrow) between entoconid and hypoconulid (GRS). (c) LM1 exhibits cusp 7 between metaconid and entoconid; also of note, LP1 fails to exhibit lingual cusp with free apex (grade 0) while LP2 exhibits odontome (GRS). (d) UI1 bilateral winging where distal margins of UI1 are everted from normal contour of parabolic arcade (white lines show angle of eversion; CGT). (e) Interruption grooves that involve both crown and root; expression almost identical between UI2 antimeres (GRS). (f) Conical peg-shaped UI2 (GRS).
Miscellany

- **Winging**: this trait is one of the few that involves orientation rather than extra cusps, ridges, roots, and so on. It is manifest primarily by the upper central incisors when the distal margins of the antimeres are everted away from the alveolus (Figure 17.3d). To be scored as winging, the feature should be bilateral, as unilateral winging can be a function of anterior tooth crowding. This trait can be scored even when the central incisors are missing, because the root sockets exhibit an orientation consistent with bilateral winging. In populations where the trait is very common (i.e., Asian and Asian-derived groups), the trait is sometimes manifest by the lower central incisors.

- **Labial convexity**: the upper central incisors of most recent human populations present a labial surface that is essentially flat. In *Homo heidelbergensis* and Neanderthals, the labial surface of the upper incisors was often markedly rounded or convex. Although far less frequent, some modern populations show low to moderate levels of labial convexity. The key tooth is UI1.

- **Interruption grooves**: on upper incisors vertical grooves may be expressed that extend from the base of the crown onto the root. For this reason, another name applied to this trait is corono-radicular groove. However, not all interruption grooves extend down to the roots, as they can be limited to the lingual surface of either the mesial or distal marginal ridge (or both in some individuals). The trait is far more common on UI2, so this is the key tooth (Figure 17.3e).

- **Peg-shaped incisor**: upper lateral incisors can, on rare occasions, be expressed as a cone rather than a spatulate tooth. These conical UI2 are also reduced in size (Figure 17.3f).

- **Canine distal accessory ridge**: the upper and lower canines can exhibit an accessory ridge on the lingual surface that falls between the essential ridge and the distal marginal ridge. This is the only morphological trait of the human dentition that exhibits sex dimorphism (Scott 1977a; Noss et al. 1983), which may be related to the sex dimorphism in canine size in modern human populations (Figure 17.4a).

- **Parastyle/paramolar tubercle**: the parastyle is expressed on the buccal surface of the upper molars. Paramolar tubercles are often considered a large manifestation of a parastyle, but these tubercles may be something different. Not uncommonly, paramolar tubercles are not expressed simply on the crown, but also have a distinct root or partial root component. One explanation is that paramolar tubercles are supernumerary teeth that are fused to one of the upper molars (often UM3; Figure 17.4b).

- **Deflecting wrinkle**: the essential ridge of the metaconid typically follows a straight course from the cusp tip to the central occlusal fossa. In some instances, this ridge deflects at about a 45% angle about halfway along its overall length. This trait is limited almost exclusively to LM1, so that is the key tooth (Figure 17.3b).

- **Distal trigonid crest**: there are two major types of trigonid crests, both of which are manifest as ridges that run from the protoconid to the metaconid. A medial trigonid crest occurs about halfway on the two mesial cusps of the lower molars. A distal trigonid crest is basically an extension and congruence of the distal accessory ridges of the protoconid and metaconid. These crests are common in early hominins, but are relatively rare in modern human populations. The key tooth is LM1.

- **Groove pattern**: in their study of hominoid teeth, Gregory and Hellman (1926) noted a consistent pattern of cusp contact in the lower molars of Miocene and modern apes. That is, cusp 2 (metaconid) and cusp 3 (hypoconid) made contact at the central occlusal fossa. As this was invariably found in association with 5
Figure 17.4  Morphological crown and root traits. (a) ASUDAS plaque showing 0 and 5 grades of presence for LC distal accessory ridge; trait can also be observed on UC (GRS). (b) Very large paramolar tubercle on buccal cusp of UM2; such forms suggest fused supernumerary tooth (CGT). (c) LM1 has six cusps while LM2 has four; for LM1, there is cusp contact between 2 and 3, producing Y-pattern, while for LM2, cusps 1 and 4 are in contact, producing X-pattern (GRS). (d) Peg-shaped UM3; in ASUDAS, variant of UM3 is noted as pegged-reduced-missing, as these are considered different grades in a continuum (GRS). (e) Four loose teeth from one individual; from left to right 1-rooted UP2, 2-rooted UP1, 2-rooted LC, and LP1 exhibiting Tomes’ root (GRS). (f) Supernumerary distolingual root produces 3-rooted lower first molar (3RM1); root traits can be scored by observing sockets even when tooth is missing (GRS).
cusps, the combination of cusp number and groove pattern resulted in the classic *Dryopithecus* Y-5 pattern. During the course of hominid evolution, cusp contact changed significantly, as cusps 1 and 4 would often meet at the central occlusal fossa. Initially this pattern was called +, but it was later referred to as the X pattern (Jorgensen 1955). The + pattern is now used for those cases where cusps 1, 2, 3, and 4 meet at a common point. In recent humans, most LM1 show a Y pattern. LM2, which often shows an X pattern, is the key tooth (Figure 17.4c).

- **Pegged–reduced–missing M3**: although members of all tooth districts can be congenitally absent (agenesis), the most common form of agenesis is manifest by third molars. Missing third molars and related expressions (pegged, reduced) are relatively common in some populations (e.g., north Asians, Eskimo-Aleuts), but are very rare in other groups (e.g., Africans, Native Australians). Although M3 can be missing in either the upper or lower jaw, the key tooth is UM3 (Figure 17.4d).

**Root Traits**

Roots do not show the complexity observed on crowns, but still provide a small suite of variables that are of utility in distinguishing among populations. The standard number of roots for human teeth is as follows: upper and lower incisors (1), upper canines (1), lower canines (1 or 2), upper premolars (1 or 2), lower premolars (1 or 2), upper molars (1, 2, or 3), and lower molars (1 or 2). Most root traits are defined on the basis of inter-radicular projections; that is, when root cones are divided for at least a quarter to a third of total root length. Lacking these projections, the root cones are fused. The two types of root variables are: root number, dictated by some combination of inter-radicular projections and fusion; and supernumerary roots.

**Root Number**

- **Lower canine root number**: one root characterizes the lower canines of individuals in most human populations. In some instances, however, the root is distinctly bifurcated into buccal and lingual root cones, producing a 2-rooted lower canine (Alexandersen 1963; Lee and Scott 2011; Figure 17.4e).

- **Upper premolar root number**: there is extensive geographic variation in upper premolar root number. These teeth can have a root cone associated with each cusp. In some populations, these cones are often fused, producing a 1-rooted upper premolar. In other groups, there is much less root fusion and the 2-rooted form is more common. On rare occasions, there are three roots (two buccal, one lingual). The key tooth is UP1 (Figure 17.4e).

- **Upper molar root number**: for UM1, there is typically a root cone associated with each cusp of the trigon, so most are 3-rooted. For UM2 and UM3, the potential for root fusion is much greater. Two-rooted molars can result from either of the two buccal roots fusing with the lingual root or through fusion of the two buccal roots. When all three roots are fused and there is no distinct inter-radicular projection, the result is a 1-rooted tooth. The key tooth for this trait is UM2. Often due to lack of space, root fusion and the 1-rooted phenotype are common in UM3.

- **Tomes’ root**: this root variant is most commonly expressed on LP1. Unlike 2-rooted UP1, where there are distinct lingual and buccal roots, a Tomes’ root is observed on
teeth with three or four radicals and is slightly off center. A Tomes’ root is manifest when the radicals show an inter-radicular projection (Figure 17.4e).

- **Lower molar root number**: LM1 typically has one broad mesial root and one distal root where each root is divided into two radicals, but there is no inter-radicular projection that produces four distinct roots. For LM2 and LM3, there can be root fusion between the buccal or lingual aspect of the two roots or between both the buccal and lingual roots, all of which produce a 1-rooted tooth. The key tooth is LM2, because LM3 is often affected by space constraints and impaction.

**Supernumerary Root**

- **Three-rooted lower first molar (3RM1)**: this trait is distinguished from root number variables because it involves an accessory disto-lingual root (Turner 1971). Although LM2 and LM3 on occasion have three roots, this trait is far more common on the key tooth LM1 (Figure 17.4f).

**Counting Methods**

In general, left and right antimeres (Chapter 7) exhibit mirror imagery in form, size, presence, and fine morphological detail. There are exceptions, however, because crown and root traits exhibit a variable amount of asymmetry (i.e., some show more asymmetry than others). Because dental traits show no side bias (with expression more pronounced on either the left or right), they exhibit “fluctuating asymmetry” rather than directional asymmetry (Van Valen 1962).

Because of the side issue, dental traits can be scored on: (1) left side only; (2) right side only; (3) all observable left and right teeth; and (4) the antimere with the most pronounced trait expression. Scott (1980) computed Carabelli’s trait frequencies using all of these methods and found that results were similar in terms of class frequency distributions and total frequencies. There are some provisos, though. Methods 1 and 2 minimize sample size unless there is the stipulation that if one side cannot be scored, expression on the antimere is counted. Method 3, or total tooth count, yields reasonable results, but artificially inflates sample size given the high level of antimeric symmetry. The individual count method is where the antimere with the highest degree of expression is scored (Turner and Scott 1977). This method maximizes sample size, avoids the problem of antimeric symmetry, and holds that the side exhibiting the greatest trait expression best reflects the underlying genotype. For these reasons, many researchers have adopted the individual count method.

**The Impact of Wear and Pathology**

Tooth wear, through attrition, abrasion, or erosion/corrosion (see Chapter 25), has a significant impact on crown traits. Burnett, Irish, and Fong (2013) demonstrated that wear can obscure morphological details and degree of trait expression. For example, when the upper anterior teeth are worn, shoveling may be evident, but scoring degree of shoveling expression is difficult if not impossible. Observers vary in how much wear they tolerate before deciding that a trait cannot be scored. This is particularly true
when sample size is small and an observer wants to score as many individuals for a specific trait as possible. As a cautionary note, this approach can have an adverse impact on sample trait frequencies and should be avoided. It is more critical to get a good frequency estimate from six individuals with very little tooth wear, as opposed to ten individuals where scoring trait expression involves some guesswork.

THE ISSUE OF THRESHOLD EXPRESSIONS

If trait expression was black and white (i.e., clearly there or not there), data collection would be a simple matter. However, crown traits often assume various shades of gray, ranging from absent through a series of grades from slight to pronounced expression. Pronounced forms are easy to score, as are intermediate expressions. The difficulty in scoring occurs at the point between trait absence and presence. The term “threshold expression” captures the essence of this scoring conundrum—is it there or is it not?

Because researchers have different ideas as to where to draw the line between trait absence and presence, a common practice is to calculate frequencies above a certain grade of expression. The term “breakpoint” is used to denote the grade where a researcher feels confident that a percentage of individuals in a sample express a trait at or above a breakpoint. For example, in a study of African samples, Irish (1993) used a breakpoint of 2+ to record shovel-shaped incisor frequencies. In samples where shoveling is more common and pronounced, like Asian and Asian-derived populations, a breakpoint of 3+ has been used (cf. Scott and Turner 1997).

KEY TRAITS AND INTER-TRAIT CORRELATIONS

In odontometrics, researchers have to deal with the issue of association, because there are significant inter-trait correlations in mesiodistal and buccolingual diameters among all teeth (Chapters 19–20). The highest correlations are often within fields (e.g., MD diameters of UM1, UM2, and UM3), but correlations between fields are significant as well. For that reason, dental measurements require methods that account for inter-trait correlations, such as principal components or factor analysis.

Although correlations in the expression of a specific tooth crown trait can be significant between antimeres, isomeres, and among members of a field (e.g., shoveling of upper and lower incisors; Scott 1977b), most traits are expressed independently of one another. For that reason, each trait can be reduced to a single frequency for biodistance analysis. Since within-field correlations are common, the best practice is to focus on trait expression on one tooth within a field. The “key tooth” for scoring trait expression can be the most stable member (i.e., polar tooth) of a district (e.g., Carabelli’s trait on UM1), or a more variable member when the key tooth shows little variation (e.g., hypocone of UM2 but not UM1). Molars are the most complex teeth in terms of cusps, ridges, and roots. Depending on the overall pattern of variation, M1 or M2 can be the key tooth for scoring expression; however, M3 should rarely be used because of the role the environment plays in producing highly variable crown and root phenotypes. The only time that M3 is a key tooth is for pegged–reduced–missing UM3.
ObserVations on Casts vs. Skeletons

A major advantage that teeth provide is their accessibility in extinct and extant populations. For the living, teeth can be directly observed intra-orally, but the most common approach is to obtain impressions from which permanent casts are produced. Museums throughout the world have thousands of crania and mandibles, making observations on teeth possible from recent times to deep in the fossil record. What are the advantages and/or differences between scoring dental casts of living individuals and skulls of past populations?

Casts
Dental casts can be produced using various colors of stone (e.g., white, yellow, blue, pink) or composite material, but color has little impact on scoring. The positives of scoring casts include: most teeth are present, including single-rooted anterior teeth; good casts record intricate details of the crown with minimal reflection; and in most instances, both the upper and lower dentition of an individual are present, so analyses that require “whole” dentitions are facilitated. The negatives of scoring casts include: casting error, which produces deformities (especially in stone) that make trait observations difficult or impossible; a synchronic perspective on dental variation; the difficulty in observing traits that have root elements (e.g., enamel extensions, interruption grooves); and that root traits cannot be scored.

Skulls
Observing teeth in actual skulls has positive and negative points. On the positive side, scoring teeth in skulls provides a temporal (diachronic) perspective to dental morphological studies; allows researchers to score root traits and traits that have crown and root components; and avoids complications introduced by reproduction. The negatives include that single-rooted anterior teeth are often lost between the field and laboratory; real teeth, if not properly curated, can dehydrate followed by enamel exfoliation; and although roots can technically be scored, curators may glue the teeth into sockets to such an extent that they cannot be observed.

inTra- and Inter-Observer Error

Early studies of tooth morphology in humans were beset by observer error. When workers scored traits as present or absent, there were disparate views as to what constituted presence. For some, any manifestation of a trait at a particular locus on a tooth was scored as present. Other researchers only scored a trait as present when there was a pronounced expression. Given different philosophies on scoring trait expression, two workers could produce vastly different frequencies for a single trait from the same sample.

In 1956, A.A. Dahlberg developed plaques designed to produce more consistent scoring practices for dental morphological traits. This approach stimulated C.G. Turner II and his students to elaborate on the Dahlberg foundation and set up classifications for a wide number of crown and root traits (Turner, Nichol, and Scott 1991). Although there are still issues with intra- and inter-observer error in scoring nonmetric (discrete) dental traits, the level of error has been greatly reduced by the wide adoption of the
Arizona State University Dental Anthropology System (ASUDAS), which includes a large number of standard plaques to help guide researchers when scoring traits.

As in most things, scoring morphology requires training, experience, and patience. With a data sheet in hand and when confronted with a cast or skull, all researchers have to make hundreds of decisions in scoring trait expression. If teeth are unworn, there are decisions to be made on threshold expressions. In teeth that are worn or show a pathology, a researcher has to decide how much modification can be tolerated to arrive at a reasonable trait score (and one that could be replicated).

Any worker embarking on a research project on tooth crown and root morphology should do a pilot study at the outset. Make observations on a given number of individuals (e.g., 30) and repeat those observations after one or more months. Issues of scoring should be taken into account in advance of a project, not after it has commenced.

**APPLICATIONS OF DENTAL MORPHOLOGY**

The study of dental morphology is far from a theoretical endeavor. The morphologic traits outlined in the ASUDAS are heritable and stable (Hillson 1996; Scott and Turner 1997), so trait frequencies in a population reflect underlying genetic patterns. This relationship allows researchers to explore questions regarding population origins, movements, and relationships. Chapter 18 addresses some of the larger themes of research in dental morphology. In this section, discussion is limited to more finely tuned questions that can be useful in archaeological and forensic contexts.

**Dental Morphology as an Archaeological Tool**

It is often important to differentiate among groups in an archaeological site. Almost any artifact or feature could potentially distinguish groups, including mortuary practices (Buikstra 1995; Emerson and Hargrave 2000; Shepherd 2005), behavioral practices (Geber 2015; Lozada, Blom, and Buikstra 1996), grave goods (Cassman 1997; Shepherd 2005; Oakland 1992; Owen 1993), and structures (Stanish 1989). Mortuary practices, including body position and grave inclusions, are of particular utility. These practices are tied to group affiliation because ritual is frequently related to underlying social order and cannot cut across groups without significant changes in symbolism (Beck 1995). This has led archaeologists to interpret burials with different configurations as belonging to different groups. For example, body position and treatment have been used to distinguish Greek and non-Greek burials in Sicily (Shepherd 1993), ethnic neighborhoods at Cahokia (Emerson and Hargrave 2000), and possible sacrificial victims from residents at the Postclassic Maya site of Wild Cane Cay (McKillop 2005).

While burial context is the best source of information regarding the material and spiritual culture of past populations (Alekshin et al. 1983), the use of archaeological evidence to demarcate biological populations can pose problems. First, establishing group membership on the basis of non-biological, cultural artifacts risks the conflation of an archaeological culture with a biological population (Sutter 2005). Such an assumption requires that the distribution of culturally diagnostic features be homogeneous across archaeological deposits (Emerson and Hargrave 2000). Second, even when a strong affiliation exists between material culture and a population, purely archaeological assessments of affinity are indirect measures. From archaeology alone,
especially in a mixed mortuary context, a researcher cannot confidently distinguish between cultural and genetic assimilation, making questions of hybridity impossible to answer (McIlvaine et al. 2014).

To answer questions of group affinity and relatedness, archaeologists have turned to bioarchaeological methods, including the use of dental morphology. The principles employed in larger comparisons of dental morphology can be applied on a smaller scale. This allows research not only to focus on relationships among culturally discrete groups but, in some cases, to explore biological subdivisions within groups considered culturally homogenous.

One application of these methods is to determine biological relatedness (or non-relatedness) in a mixed mortuary context. McIlvaine and colleagues (2014) examined a cemetery at the Greek colony of Apollonia, Albania to assess to what degree inter-breeding may have occurred between indigenous Illyrians and colonial Apollonians. Greek colonization in the Mediterranean was widespread and enduring (Galaty 2002; Lafe and Galaty 2009; van Dommelen 2012); however, the prevalence of population mixing has rarely been assessed through any direct measure. Most commonly, the colonizers were Greek men who married local women; therefore, a certain degree of inter-breeding is expected (Antonaccio 2003; Hodos 1999; Tsetskhladze 2006), but has not been systematically studied. Given the large sphere of influence exerted by Hellenistic culture in the Mediterranean, the presence of Greek goods in a cemetery does not necessarily imply colonization or migration by Greek individuals (van Dommelen 2012).

Material culture and mortuary practice are among the most common methods used by archaeologists for assessing population affinity. This is no less true on the Balkan Peninsula, where Greek versus non-Greek status has traditionally been accomplished using grave goods (Leighton 1999; Shepherd 1993). Greek goods are often intermixed with local products in cemeteries within the area of Greek colonization, but intermarriage is only one possible interpretation of these assemblages (van Dommelen 2012). Given the nature of Greek colonization, it is equally likely that such a mix of grave goods is the result of trade, assimilation, or cultural hybridization (Graham 1984, 1995; Hodos 1999).

McIlvaine and colleagues (2014) utilize dental morphology, in combination with biodistance statistics, to answer questions about the cultural patterns of ancient Greek colonization. Biodistances were calculated among Illyrians, colonial Apollonians, and Corinthians (the Greek parent population of the Apollonian colony), primarily on the basis of the visual inspection of 28 dental traits from the ASUDAS and the application of the pseudo-Mahalanobis’ $D^2$ statistic (McIlvaine et al. 2014). Traits were dichotomized according to existing procedures (Irish and Konigsberg 2007; Scott and Turner 1988; Turner 1987) to increase the validity of the pseudo-Mahalanobis’ $D^2$ statistic. Logistic regression was used to separate the Illyrian and Corinthian samples. Apollonians were then classified based on affinity to one of the two parent groups (McIlvaine et al. 2014). Based on gross observations of dental morphology, Apollonian individuals rarely exhibited the expected expression of traits—intermediate to Corinthian and Illyrian populations (McIlvaine et al. 2014). The results from the pseudo-Mahalanobis’ $D^2$ statistic and logistic regression are more telling. Through multiple iterations, using differing numbers and combinations of traits, the Apollonians are more similar to indigenous Illyrians, indicating that Corinthians did interbreed with local Illyrians. The mixed burial assemblages found in the Apollonian cemetery are likely the result of genetic as well as cultural exchange between the two populations (McIlvaine et al. 2014).
This study by McIlvaine and colleagues, and others like it (Sutter and Verano 2007), illustrates the utility and potential hazards of using dental morphology at the small scale. The efficacy of dental variation for the purposes of calculating biodistance is dependent on the degree of variation in the populations studied. When comparing populations that are phenotypically distinct, a relatively small sample can effectively demonstrate differences. When populations are phenotypically similar, as in the case of Illyrians and Greeks (McIlvaine et al. 2014), large samples and more traits are needed to reveal differences.

When populations are separated by vast geographic and biological distances, as in the “big picture” questions, differences in dental morphology are easier to observe and quantify (Chapter 18). On a smaller scale, differences are less obvious, and common ancestry may be an influential factor. Beyond the continental level of analysis, more refinement is needed to observe and record existing dental variation. The research in this section demonstrates a popular direction in dental anthropology. Many of the “big picture” questions have been answered. The challenge to the dental anthropologist is to answer questions with a more specific focus by refining scoring methods and statistical approaches.

**Dental Morphology in a Forensic Context**

Analysis of dental morphology is a powerful tool for determining population affinity. By contrast, the primary goal of the forensic anthropologist is individual identification. Dental morphology may play a critical role in the future of forensic ancestry estimation. Together with the traditionally used cranial traits, dental traits provide a multitude of features that can be used to assess population affinity. They are particularly useful in forensic cases, where fragmentary and damaged remains are common. Recent methods have applied a statistical framework to the traditional trait list method. The next logical step is to incorporate dental morphology into existing methods, potentially increasing the accuracy and utility of these traits in ancestry estimation (Edgar 2009, 2013; Chapter 21).

**REFERENCES**


Jorgensen (1955) Ref to come.


