Part I

Introduction

During the first half of the twentieth century, scoring dental morphology was idiosyncratic. That is, researchers who wanted to study morphology would decide which traits they wanted to score and the system of recordation for scoring them. Except for basic observations such as molar cusp number, there was relatively little agreement on how to score these traits. Hrdlička (1920) was among the first to realize that observations had to be fine-tuned for shovel-shaped incisors, which showed extensive variation in presence expressions, with a dramatic difference between American whites and Native Americans. Toward this end, he developed a four-grade scale that included no shovel, trace, semi-shovel, and full shovel. Hrdlička (1924) also used a rank scale to score the precuspidal fossa (i.e., anterior fovea). He recognized that tooth crown traits were not simply discrete, presence/absence variables, but felt the need to recognize the variability of presence forms, which often ranged from slight to pronounced. Because of its wide range of variation in American whites and Europeans, Carabelli's trait was often scored on a ranked scale (e.g., Dietz 1944, Kraus 1951), but these scales varied by observer. Beyond these examples, many traits were scored as present or absent even when presence forms varied from slight to pronounced (or small to large). The problem was that individuals had different ideas as to what constituted trait presence, and the result was widely contrasting trait frequencies for closely related groups.

Albert A. Dahlberg, a dentist by training and trade but one blessed with an inquisitive anthropological and biological mind when it came to teeth, recognized the pitfalls and inconsistencies in scoring dental morphology. To rectify the situation, he set himself the task of developing ranked standards for 16 traits (Dahlberg 1956). After setting up ranked scales, he duplicated them in plaster and distributed them to dental researchers throughout the world. This was the first necessary step to reducing inter-observer error in scoring tooth crown traits (he did not include roots in this effort). Although observer error was resolved to some extent, it was not eliminated altogether.

Utilizing the Dahlberg standards in his dissertation on Arctic populations, Christy G. Turner II (1967a) wanted to take the study of dental morphology to another level. Al Dahlberg and Bertram Kraus both played big roles in this development as they sought to unravel the genetics of morphological trait expression, with some hope these efforts would eventually mirror the rapid rise in serological genetics in the early 1950s. The first efforts by Turner (1967b, 1969) to use crown and root traits in microevolutionary studies set the stage for addressing a broad range of anthropological problems through dental morphology. Even so, if dental morphology was to play a more significant role in the study of human variation, more traits had to be defined, more standards had to be established, and general principles had to be developed.

In 1970, Turner developed the first two plaques (lower molar cusp 6 and cusp 7) in what was to become known as the Arizona State University Dental Anthropology System. Going beyond crowns, Turner (1971) studied roots and laid out the three-wave model for the peopling of the Americas based on the distribution of three-rooted lower first molars (3RM1). At the same time, Scott (1973) developed a number of standards for his dissertation on dental morphology that focused on a genetic analysis of families and variation among native populations of the American Southwest. From roughly 1970 to 1990, Turner worked with a number of other graduate students to develop standard plaques for a variety of crown and root traits.

Prior to Turner's work, dental morphology was mostly descriptive and had very little impact on the broader world of physical anthropology. That changed substantially in the 1980s when teeth played a key role in discussions of the peopling of the New World, the dental dichotomy in Asia, and the settlement of Australia and the Pacific. Even geneticists allow that their findings are often in concert with those of dental morphology (cf. Reich *et al.* 2012). Now dental morphology is being used in a wide variety of contexts, from intra-cemetery analysis and regional microdifferentiation to ancestry estimation in forensic anthropology.

Why a Guidebook?

Although serendipitous, the production of this guidebook marks the 25th anniversary of "Scoring procedures for key morphological traits of the permanent dentition: the Arizona State University dental anthropology system" (Turner *et al.* 1991). This article has received a great deal of attention since its publication, being cited almost 400 times and viewed over 1600 times (academia.edu). Many students and researchers have followed the methodological guidelines set forth in that article, used along with the standard plaques distributed by Arizona State University (ASU) to over 400 researchers throughout the world.

Given the success of the 1991 article, some might say "let sleeping dogs lie." How can you improve on something so widely read and followed? GRS raised this issue with Christy Turner in 2013, just months before his passing, and Turner agreed that the methodological guidelines set forth in the original article could be expanded and improved upon. For example, the 1991 article only had four photos. Most variables were briefly described but not illustrated. That was due, in large part, to the limitations in the production of an edited volume (Kelley and Larsen 1991). An authored book has fewer limitations regarding illustrations, and Cambridge University Press has allowed us to take advantage of that in this volume.

The goal of this guidebook is to facilitate more research on crown and root trait variation throughout the world. Over several decades, Turner made observations on hundreds of samples and over 30,000 individuals, with an intensive focus on the New World, Asia, Australia, and the Pacific. His observations on Europeans were limited and on Africans even more limited. JDI has remedied the paucity of dental morphological observations on African populations (Irish 1993, etc.), but there is much more work to be done in other parts of the world. Tens of thousands of human skeletons/dental casts/loose teeth and hundreds of anthropological questions are waiting to be pursued through the assessment of crown and root morphology.

The old bugaboo of inter- and intra-observer error during the first half of the twentieth century remains a minor issue in the age following standardization. Making dental observations on crown and root traits still requires training and experience, but this is true in all scientific endeavors. The primary goal of this volume is to help students and researchers alike make systematic observations on dental morphology with a minimum of error. Before proceeding with individual trait descriptions, we provide basic terms required for research in dental anthropology and morphology.

Terminology

Teeth and Fields

Mammals typically have four types of teeth: cutting teeth at the front of each jaw (incisors), piercing teeth immediately behind the cutting teeth (canines), grinding teeth at the back of the jaws (molars), and all-purpose teeth that can either slice/dice (carnivores) or grind (herbivores) between the canines and molars (premolars) (Hillson 2005). In developing the concept of dental fields, P.M. Butler (1939) only included incisors, canines, and molars, given that premolars could develop either in line with the grinding molars or with the cutting, slicing anterior teeth. In a classic paper adapting the concept of morphogenetic fields to the human dentition, Dahlberg (1945) included premolars as a separate field along with incisors, canines, and molars.

Although dental clinicians use numbers to denote specific teeth, this system is less useful in anthropology. Many researchers use a letter to describe jaw location (U = upper; L = lower), another letter to describe tooth type (I = incisor; C = canine; P = premolar; M = molar), and a number to note a tooth's position within a morphogenetic field (e.g., 1 = central incisor, first molar). The ancestral mammalian dental formula of 3–1–4–3 involved some tooth reduction during primate evolution. Catarrhine primates (Old World monkeys and apes) lost their first two premolars (P1, P2), so researchers who specialize on primate and fossil hominin dentitions refer to the two premolars in hominoids and hominins as P3 and P4. Although there is no argument that the first two premolars were lost during the course of evolution, many anthropologists who focus on recent human populations refer to the premolars as P1 and P2. That is the convention we adopt in this guidebook. Although antimeric asymmetry does pose minor issues in studies of dental morphology, we are not overly concerned with designations

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of right and left teeth. For example, we use UI1 (upper central incisor), LP1 (lower first premolar), UM3 (upper third molar), etc., without designating left or right.

Orientation

Crowns and roots are often described in terms of their relationship to the midline of the upper or lower jaw and direction toward the lips/cheeks or tongue (Figure i). The midline runs between the central incisors of both jaws. When a surface, cusp, or trait runs in the direction of or toward the midline, the term mesial is used to indicate direction. When these same features run away from the midline (toward the back of each quadrant), the term of orientation is distal. The surface of all teeth in both jaws on the inside of the mouth and toward the tongue is lingual. For the cheek teeth (premolars and molars), the surface in contact with the cheek is buccal. For anterior teeth (incisors and

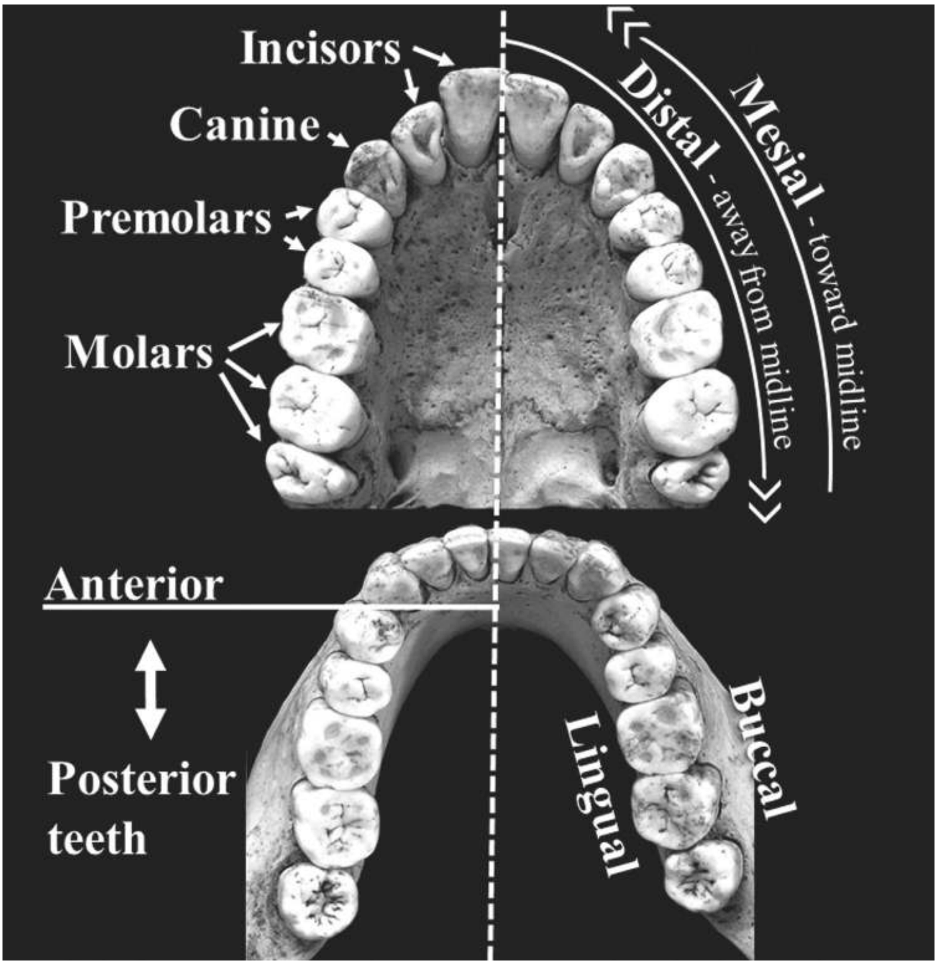

Figure i Basic terms of orientation for upper and lower teeth.

canines), the surface in contact with the lips is labial. To avoid the use of two different terms, dental anatomists combine labial and buccal under the term facial (cf. Carlsen 1987). These terms are often used in conjunction to pinpoint location on a crown (e.g., mesiolingual cusp) or root (e.g., distobuccal root).

The left and right quadrants of either jaw have teeth that are, for the most part, mirror images of one another. The corresponding right and left teeth, e.g., right upper first molar and left upper first molar, are antimeres. Corresponding teeth in the two jaws, or isomeres, are not mirror images (e.g., upper left central incisor, lower left central incisor). The teeth in the two jaws evolved to enhance masticatory efficiency so they fit together (ideally), but they differ in size and morphology. The surfaces of the crowns that come in contact when the upper and lower jaws occlude are incisal for the anterior teeth (incisors and canines) and occlusal for the posterior teeth (premolars and molars).

Lobes and Cusps

In *Dental Morphology*, Carlsen (1987) lays out general dental anatomical principles that are of utility in the study of nonmetric crown and root trait variation. Early dental anthropologists used the term cusp to describe the major units of each tooth. Carlson also discusses cusps but in the context of another macromorphological unit, the lobe (Figures ii, iii, iv). Each tooth, for example, is made up of one to five lobes. The anterior teeth have one lobe, the premolars basically two lobes, and the molars four to five lobes, with often fewer in the second and third molars. For the anterior teeth, there is a centrally located essential lobe segment and two accessory lobe segments, one mesial and one distal. Lobe segments have both facial and lingual components, each of which is called a lobe section. On the essential lobe section of canines and posterior teeth, there is usually an essential ridge that extends up to the cusp tip. The accessory lobe sections end at a point lower than the cusp tip of the essential lobe. Trichotomous lobes are not as evident in the incisors, although the divisions are reflected at an early age in incisal mamelons. For the upper canine, the essential ridge is a prominent feature of the crown and is distinctly set off from the mesial and distal lobe sections. Although the lower canine is spatulate and does not usually exhibit a distinct essential ridge, it still follows this basic form. For both canines, it is not unusual to find a distinct ridge on the lingual aspect of the distal accessory lobe section, referred to as the distal accessory ridge. This has two connotations. It specifies the location on the tooth and also notes that it is accessory, meaning that it may or may not be present (i.e., a nonmetric trait).

The cusps of the upper molars follow the Cope–Osborn nomenclature (Gregory 1916) (Figure v). The trigon, which has deep roots in the mammalian fossil record, has three major cusps: the protocone (lingual), the paracone (mesiobuccal), and the metacone (distobuccal). The hypocone is an additional cusp that was added in many mammalian lineages on the distolingual corner of the trigon (Hunter and Jernvall 1995). The cusps are numbered relative to their presumed appearance in the mammalian fossil record (protocone = 1, paracone = 2, metacone = 3, and hypocone = 4). Each of

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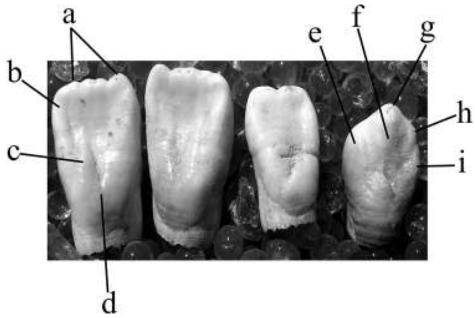

Figure ii Unworn upper central incisors, a left upper lateral incisor, and a left upper canine used to illustrate basic dental terms: (a) mamelons; (b) distal marginal ridge; (c) tuberculum projection; (d) basal cingulum; (e) mesial marginal ridge; (f) essential ridge of lingual lobe section; (g) cusp; (h) distal accessory ridge; (i) distal marginal ridge.

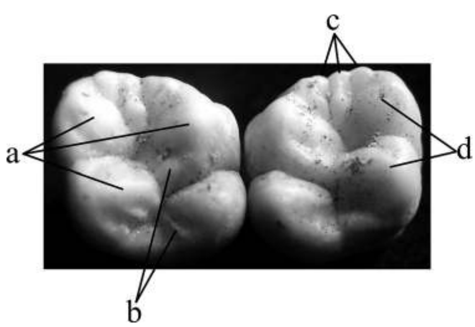

Figure iii Unerupted upper first molars used to illustrate: (a) essential ridges of the three major cusps of the trigon; (b) accessory ridges; (c) marginal ridge complex with three mesial marginal tubercles (trait 17); (d) cusp tips of the paracone and metacone.

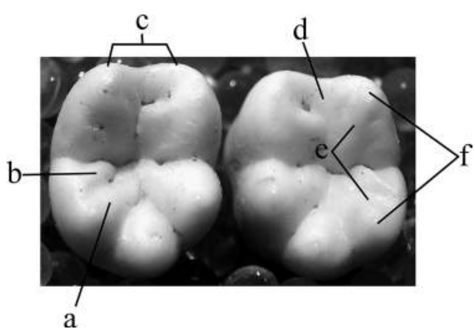

Figure iv Unerupted lower first molars used to illustrate: (a) essential ridge of hypoconid; (b) mesial accessory ridge of hypoconid; (c) marginal ridge complex; (d) anterior fovea; (e) essential ridges of protoconid and hypoconid; (f) cusps of protoconid and hypoconid.

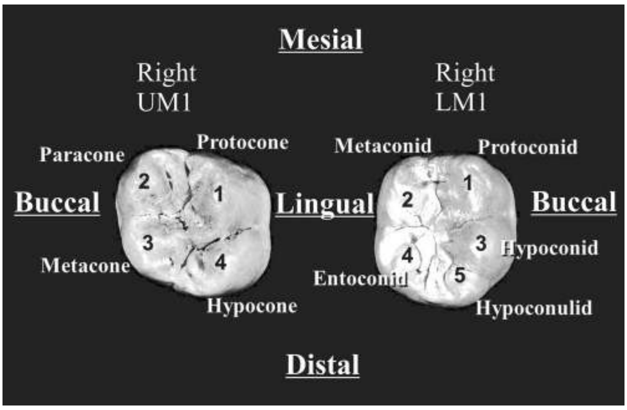

Figure v Cusp names and numbers for upper and lower right first molars.

the major cusps of the trigon have essential and accessory lobe segments which in turn have facial and occlusal lobe sections. For each cusp, the essential ridge ends in an elevation that is the highest point of that lobe section, which in the Carlson system is the cusp of the lobe segment. As with the upper canine, the essential ridge is flanked by accessory lobe sections that may or may not exhibit accessory ridges.

The evolution of the lower molars was more complicated than that of the upper molars because lower molars have two major components rather than one. The mesial component is the trigonid, made up of the protoconid (cusp 1, mesiobuccal) and the metaconid (cusp 2, mesiolingual). There was a third cusp (paraconid) that was situated between and anterior to the protoconid and metaconid, but this cusp was lost in primate evolution during the Oligocene. Distal to the trigonid is the talonid. Opposite of the trigonid, the talonid started out with two cusps, the hypoconid (cusp 3, distobuccal) and the entoconid (cusp 4, distolingual), but eventually added the hypoconulid (cusp 5), situated between and posterior to the hypoconid and entoconid.

By convention, large cusps of the upper dentition are referred to as cones while those in lower jaw are conids. The same distinction is maintained for minor features (e.g., styles or conules in the upper jaw, stylids or conulids in the lower jaw). These terms recur frequently in trait descriptions. Other terms, such as accessory ridges and inter-segmental grooves, apply to both upper and lower teeth.

While crowns are divided into lobes, roots are divided into units called cones. The number of cones and roots of each tooth is dictated by the presence of root grooves and inter-radicular projections (Figure vi). A groove, for example, divides the cones but they remain coalesced. An inter-radicular projection is a bifurcation of root cones into two or more separate roots (sometimes called separation structures). An upper incisor typically has two root cones, but these rarely show a bifurcation. The lower canine, on the other hand, usually shows two root cones but in some groups there is an inter-radicular projection that separates the cones, producing two-rooted lower canines (another nonmetric trait).

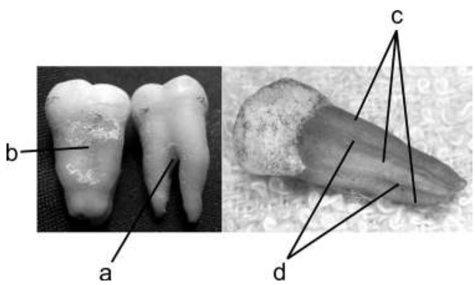

Figure vi Upper premolars used to illustrate: (a) inter-radicular projection; (b) root groove separating two root cones; (c) three root cones; (d) two root grooves.

Cones separated from other cones by root grooves but without separation structures are called radicals. On the original Arizona State University Dental Anthropology System (ASUDAS) scoring sheet (Turner *et al.* 1991), there was a row for the number of radicals exhibited by each tooth. To our knowledge, Turner amassed a great deal of information on radical number in world populations but never tabulated this information, so its significance is unknown. Researchers can score this variable, but we do not include it in the following trait descriptions.

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NOTES