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Frequency of Occurrence and Degree of Expression of the Parastyle in Several Modern Human Populations

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Keywords: dental morphology, humans, paramolar cusps, genetics, supernumerary teeth

ABSTRACT The aims of this study are to describe the frequency of occurrence and degree of expression of the parastyle in six different ethnic groups; to assess inter- and intra-observer errors when scoring the feature; and to compare the expression of the feature in a small number of twin pairs. Dental casts were examined for evidence of the parastyle from samples available in the Adelaide Dental School. A dental plaque developed by Katich & Turner was used to standardize scoring. The highest percentage frequency of parastyle occurrence was found in a sample of European twins with a value of 1.7%. The buccal aspect of the mesiobuccal cusp of the permanent maxillary right second molar was the most common site for the parastyle. Inter-observer reliability in scoring was lower than intra-observer reliability. In 10 pairs of twins (seven pairs of monozygotic [MZ] twins and three pairs of dizygotic [DZ] twins) only two pairs of MZ twins showed concordance for presence of the parastyle. The expression of parastyles likely results from a complex interaction of genetic, epigenetic, and environmental influences during dental crown development. There may be a relationship between parastyles and supernumerary teeth that are occasionally located buccally to the maxillary molar teeth.

Since Louis Bolk (1916) first described an unusual projection on the buccal surfaces of maxillary molar crowns, researchers have had trouble explaining its etiology and giving the feature an appropriate name. The trait has been termed a maxillary paramolar cusp, paramolar tubercle, stylar anomalous cusp, supernumerary inclusion, and a parastyle. There are few more enigmatic features in the human dentition. Albert Dahlberg was aware that some system of identification needed to be established to standardise methodology and he devised his own descriptive method (Dahlberg, 1945). The importance of Dahlberg's terminology was that he considered the feature in terms of its location on the mesiobuccal cusp of the permanent maxillary second and third molars (that is, on the paracone or cusp 2) and, by applying his paleontological knowledge, he referred to it as a parastyle (Dahlberg, 1945). A similar feature was noted in a corresponding position on the protoconid of the lower molars and Dahlberg called it a protostylid.

Another difficulty encountered by researchers when studying parastyles has been how to describe their size objectively. These traits are difficult to assess with only limited guidelines (e.g., a single standardised plaster reference plaque) for comparison. Many previous references to parastyles have been case reports or linked to descriptions of the management of supernumerary teeth that have included photographs and radiographs as illustrations (Nagaveni et al., 2010; Parolia et al., 2011; Duddu et al., 2012; Nabeel et al., 2012; Jain et al., 2014; Shuangshuang et al., 2016).

A smaller number of more detailed studies have provided insights into the frequency of occurrence and variation in expression of the parastyle in different human populations. The frequency of occurrence of the parastyle has been estimated to vary from zero to 0.1% in first molars, 0.4 to 2.8% in second molars and 0 to 4.7% in third molars (Kustaloglu, 1962). These data were obtained from analyses of material representing recent *Homo sapiens* (Whites, American Blacks, Melanesians, Filipinos, Hawaiians, Middle Easterners [Kish], and Native Americans [Southwest Indians, Northwest Coast Indians, Peruvians]). Kustaloglu (1962) found that the parastyle was more common in Native Americans than the other population groups (2.6%).

A retrospective study of the parastyle in children

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aged two and eight years looked at factors relating to parastyle expression, including unilateral versus bilateral positioning in the dental arch, its frequency in both males and females, and its occurrence in primary and secondary dentitions (Nagaveni et al., 2017). In conclusion, the authors noted the parastyle was extremely rare in the primary dentition and that findings were inconclusive as to the other areas under review. Importantly, the difficulty in scoring the parastyle and the need to provide a more accurate method of measuring the feature were emphasized (Nagaveni et al., 2017).

The aims of this study are to describe the frequency of occurrence and degree of expression of the parastyle within and between six different ethnic groups; to assess inter- and intra-observer errors when scoring the feature; and to compare the expression of the feature in a small number of twin pairs. Our specific objectives are as follows: (1) make comparisons of the frequency of occurrence and degree of expression of the parastyle between primary and permanent dentitions of the same individuals (based on a study sample of twins); (2) compare expression on the first, second and third molars; and, (3) make comparisons between maxillary and mandibular molar teeth, as well as between right and left sides and between males and females. Another objective is to assess inter- and intra-observer errors when scoring the feature to determine the usefulness of the plaque developed by Katich and Turner when examining the parastyle. A final objective is to explore the possible roles of genetic, epigenetic and environmental influences on observed variation of the parastyle by comparing the expression of the feature in a small number of twin pairs. Finally, some thoughts about the etiology of the feature and its relationship to supernumerary molar teeth are provided, based on a threshold model of dental expression (Brook, 1984; Brook et al., 2014a, b).

Materials and Methods

Dental casts representing both sexes were examined for evidence of the parastyle from samples of six different ethnic groups available in the Murray Barrett Laboratory, Adelaide Dental School, The University of Adelaide, by a single trained observer (GS). The frequency of occurrence and degree of expression of the trait were calculated for each of the ethnic groups. Casts showing the presence of a parastyle were selected for further study.

The dental plaque developed by Katich & Turner in 1974 (Turner et al., 1991) was used to standardize scoring of the feature and to determine degrees of expression (Fig. 1). Reference was also made to written descriptions of the appearance of the parastyle, ranging from a small pit to a large cusp-like structure, provided by Turner et al. (1991). The reference plaque includes the following categories:

0 - The buccal surfaces of cusps 2 and 3 are smooth.
1 - A pit is present in or near the buccal groove between cusps 2 and 3.
2 - A small cusp with an attached apex is present.
3 - A medium-sized cusp with a free apex is present.
4 - A large cusp with a free apex is present.
5 - A very large cusp with a free apex is present. This form usually involves the buccal surface of both cusps 2 and 3.
6 - An effectively free peg-shaped crown attached to the root of the third molar is present. This rare condition is not shown on the plaque.

Whilst reference to the plaque was useful in providing a standard for scoring, it only showed five variations of parastyle expression and was therefore limited in the information it provided.

The method used in the production of the dental casts was uniform for all the groups studied. Alginate impressions were obtained of the subjects' dentitions

Figure 1. The dental plaque developed by Katich and Turner in 1974, used to standardize scoring of the parastyle and to delineate its degrees of expression.

and these impressions were poured using dental stone according to the manufacturer's specifications. After the dental stone had set, the impressions were removed from the casts and trimmed prior to examination.

The Australian Aboriginal dental casts were obtained from a longitudinal growth study of Central Australian Aboriginals conducted at Yuendumu Settlement in the Northern Territory of Australia, between the years 1951-1972 (Brown et al., 2009). The ages of the subjects ranged between 5 to 77 years, with most being teenagers. The sample totalled 405 subjects.

The same method of dental cast production was followed for the following ethnic groups: Malay Malaysians, 293; Chinese Malaysians 196; Indian Malaysians, 253; and Orang Asli, 71. These casts were collected as part of a PhD study that investigated dental variation in Malaysian schoolchildren with application to human identification (Khamis, 2005). The ages of the subjects ranged between 12 and 51 years, and the sample totalled 813 subjects.

Dental casts of twins of European ancestry and known zygosity, who are involved in an ongoing study of orofacial morphology and growth and oral health at the Adelaide Dental School, The University of Adelaide, were also included in this study (Hughes et al., 2014; Townsend et al., 2015). A total of 620 subjects from Cohort 1 were scored for parastyles with the casts of twin pairs sorted randomly and the operator blinded to zygosity. The twins were all of European ancestry and ranged in age from 6 to 63 years. The total number of dental casts examined in all of the samples was 1838.

Using the parastyle plaque of Katich and Turner, the question of intra- and inter-observer reliability was assessed with three experienced observers scoring the feature twice. The period between each observer score was at least two weeks enabling an assessment of concordance/discordance to be performed. It also gave the observers the ability to assess the associated criteria for determining different degrees of parastyle expression. Deliberately, the three operators who scored the parastyle, although being experienced dental anthropologists, had no training together prior to each scoring the feature independently, so that the value of the plaque as a means of standardising across different observers could be investigated.

Results

The frequencies of occurrence (prevalence) of the parastyle in the six different ethnic groups are presented in Table 1. Table 1 shows that the highest percentage frequency of parastyle occurrence was in the sample of European twins with a value of 1.6%. This was followed by the Australian Aboriginal sample with a frequency of 1.5%. The Malay Malaysians and Indian Malaysian groups showed fewer parastyles with only 0.3-0.4% of individuals displaying the trait, while no Chinese Malaysians were found to display the feature. The Orang Asli group result was 1.4% but the sample size was relatively small.

TABLE 1. Prevalence of parastyles in different ethnic groups

Ethnic group	n	present	%
Australian Aboriginal	405	6	1.5
Malay Malaysian	293	1	0.3
Chinese Malaysian	196	0	0.0
Indian Malaysian	253	1	0.4
Orang Asli	71	1	1.4
European Twins	620	10	1.6

The degrees of expression of the parastyle in the different study samples are shown in Table 2 and some examples of the expression of the feature are provided in Figure 2.

Only one individual (T234A) showed evidence of the parastyle in the primary dentition, with the feature being displayed on the primary maxillary right first molar. Across all ethnic groups, the buccal aspect of the mesiobuccal cusp of the permanent maxillary right second molar was the most common site for the parastyle, with 13 observations. Other teeth that showed the trait were the permanent maxillary right first molar (score: 1), permanent maxillary left second molar (score: 6), permanent maxillary right third molar (score: 1), and the deciduous maxillary right first molar (score: 1). Given that most of the subjects included in this study were children or young adults there were few cases where third molars could be scored.

Using the Katich and Turner plaque, degrees of expression of the parastyle ranging from scores of 1 to 6 were recorded. There were similar numbers of males and females displaying evidence of the parastyle (11 males and 8 females). Scores for parastyle expression that highlight intra- and inter-observer reliability are given in Table 3.

Within observers, there was no difference that was greater than one grade between the first and second scores. The difference in scoring between observers was never greater than two grades. In 17 cases, there were scoring differences noted between the three observers. This greater difference between observers' scores occurred seven times. Scorer 1 displayed four

TABLE 2. Frequency of occurrence and degree of expression of parastyles in different ethnic groups

Ethnic Group	Tooth affected	Degree	Sex
Australian Aboriginal			
Δ9	17	2	M
Δ17	17	5	M
Δ72	17, 18	3, 3	F
Δ119	17	2	M
Δ338	17	5	F
Δ578	17	2	M
Malay Malaysian			
MM 165	17, 27	2	M
Orang Asli			
OA 3	17	2	M
Indian Malaysian			
IM 105	17	2	F
European Twins			
T67B	17	3	M
T85B	17, 27	5, 5	M
T136B	27	5	M
T163B	17	2	M
T192B	27	4	F
T226A	27	4	F
T234A	54	3	F
T256A	16, 26	1	F
T262B	27	5	M
T304B	17	2	M

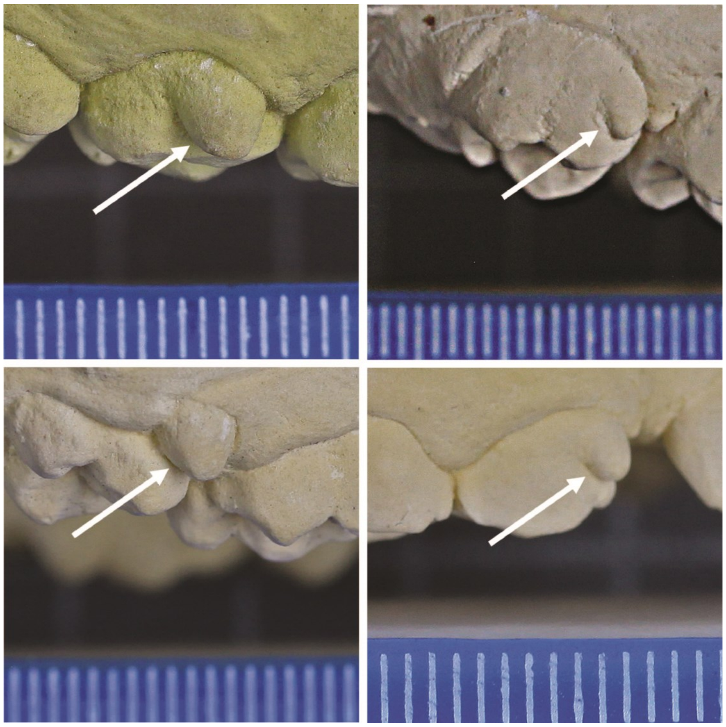

Figure 2. Some examples of the expression of the parastyle. Upper left - Australian Aboriginal male, Δ17, grade 5 on tooth 17; Upper right - Indian Malaysian female, IM 105, grade 2 on tooth 17; Lower left - Twin T85B male, grade 5 on tooth 17; Lower right - Twin T234A female, grade 3 on tooth 54.

different scores from scorers 2 and 3, scorer 2 displayed four different scores from scorers 1 and 3, and scorer 3 displayed nine different scores from scorers I and 2.

With regard to the sample of twins of European ancestry, after scoring one member at random from each pair of twins, the co-twins of all those twins who displayed the parastyle were examined. Table 4 shows that in the 10 pairs examined (seven pairs of MZ twins and three pairs of DZ twins), only two pairs of MZ twins showed concordance for presence of the parastyle. In one of these pairs (T256), both members of the pair not only showed evidence of parastyles in their maxillary molars but also displayed protostylids on their permanent lower first molars.

Discussion

When comparing the prevalence of the parastyle between ethnic groups under investigation it is interesting to note that two distinct groupings were evident. The Malaysian groups showed fewer parastyles than either the Australian Aboriginals or the European twins, although the sample sizes of the Malaysians were smaller. It is acknowledged that the inclusion of both members of twin pairs could have increased the prevalence estimates in this group if there was evidence of concordance between MZ co-twins for parastyle occurrence. However, only two pairs of MZ twins showed concordance for the feature. The Malaysian groups conformed reasonably closely with the values for parastyle occurrence on permanent molars reported by Kustaloglu (1962) that ranged from 0.1% - 4.7%. Scott et al. (2018) provide a table of paramolar tubercle frequencies compiled from the C.G. Turner II database for over 9000 individuals distributed across 23 geographic groupings. The world average for all

TABLE 3. Intra- and inter-observer reliability for scoring parastyles

Ethnic Group	Cast ID	Location	Scorer 1		Scorer 2		Scorer 3	
			1st	2nd	1st	2nd	1st	2nd
Australian Aboriginal	∆9	17-MB	2	2	2	2	2	2
	∆17	17-MB	5	5	5	5	5	5
	∆72	17-MB	3	3	3	3	2	1
		18-MB	3	3	3	3	5	5
	∆119	17-MB	2	2	2	2	1	2
	∆338	17-MB	5	5	5	5	5	5
	∆578	17-MB	2	2	2	3	2	1
Malay Malaysian	MM 165	17-MB	2	2	2	2	2	2
		27-MB	2	2	3	3	3	3
Orang Asli	OA 3	17-MB	3	3	2	3	1	1
Indian Malaysian	IM 105	17-MB	2	2	2	2	2	2
European Twins	T67B	17-MB	3	3	4	5	3	3
	T85B	17-MB	6	6	5	5	5	5
		27-MB	6	6	5	5	5	5
	T136B	27-MB	4	5	5	5	5	4
	T163B	17-MB	2	2	3	4	2	2
	T192B	27-MB	3	3	4	4	4	4
	T226A	27-MB	4	4	4	4	4	4
	T234A	54-MB	3	4	3	3	2	2
	T256A	16-MB	1	1	1	1	2	2
	T262B	27-MB	4	4	5	5	4	5
	T304B	17-MB	2	2	2	2	1	1

groups was 1.58%. Relative to the groups in this study, Australians had incidence prevalence of 1.8%, Europeans 2.17% (Western) and 0.63% (Eastern), East Asians 1.6%, and Southeast Asians 2.27% and 1.75%, for early and recent groups respectively. These values are in general accord with our findings on recent populations. As the trait generally varies between one and three percent, further studies of large samples are needed to determine whether there are significant differences in parastyle frequency and degrees of expression between different human populations.

The finding that most of the parastyle observations occurred on the right side of the dentition suggests that there could be some directional asymmetry involved, although there is very little evidence to support consistent expression of directional asymmetry in any dental crown morphological features (Scott et al., 2018).

There did not appear to be any significant difference in parastyle frequency of occurrence between the sexes. Table 2 shows that a similar number of males and females displayed the feature, and that the size and shape of the feature did not appear to differ between males or females, so sexual dimorphism was not evident in our study. However, given the very small number of individuals who show parastyles, very large sample sizes are needed to detect systematic differences between the sexes.

It was evident in the scoring of the parastyle that difficulties arose in determining the size of the feature. We suggest a new plaque be developed that has the capacity to improve accuracy in scoring. The present plaque provides only one example of the degree of parastyle formation in the six categories mentioned.

The fact that the teeth used to construct the plaque vary widely in terms of their size and shape makes it difficult to score the relative size of the parastyle when

TABLE 4. Expression of parastyle in twin pairs

Twin ID	MZ/ DZ	Co-Twin ID	P/A	Concordant/ Discordant
T67B	DZ	T67A	A	D
T85B	MZ	T85A	A	D
T136B	MZ	T136A	A	D
T163B	MZ	T163A	A	D
T192B	DZ	T192A	A	D
T226A	DZ	T226B	A	D
T234A	MZ	T234B	P	C
T256A	MZ	T256B	P	C
T262B	MZ	T262A	A	D
T304B	MZ	T304A	A	D

P=present, A=absent

extrapolated to other teeth that are under investigation. We suggest providing more than one example of the categories of the parastyle to highlight the extent of the variation within a category. It would also be helpful to have stereoscopic images of these different variations in digital form that could be viewed from different perspectives using computer technology.

As shown in Table 4 there were seven MZ twin pairs and three DZ pairs examined, with only two pairs of MZ twins showing concordance for parastyle occurrence. Given that MZ twins share all of their genes, while DZ twin pairs, on average, share only 50% of their genes, one would expect a higher concordance of parastyle occurrence within MZ pairs if there was a strong genetic basis to the feature. The lack of concordance suggests that variation in parastyle occurrence and expression is likely to reflect mainly epigenetic and/or environmental influences.

The tendency for the strongest expression of the parastyle to have characteristics similar to supernumerary teeth that form buccally to the permanent molars (i.e., apparently with separate crown formation although possibly fused roots), suggests that the feature may conform to the upper end of the multifactorial unifying aetiological model of dental development (Brook, 1984; Brook et al., 2014a, b) that posits a relationship between tooth size, shape, and presence or absence. It is possible that the strongest expression of the parastyle falls just to one side of a threshold above which a supernumerary molar tooth is formed. Further studies of the associations between tooth size, parastyle expression and supernumerary tooth prevalence within individuals would help to clarify this issue. One of the authors (GRS) has noted structures similar to paramolar tubercles on the lingual surface of the maxillary molars and both buccal and lingual surfaces of the mandibular molars. Buccal manifestations on the lower molars are not protostylids, which are expressed in a constant position on the buccal surface of the protoconid and are less pronounced than lower molar 'pseudo-paramolar' tubercles. These diverse expressions may represent different developmental processes: some of the appearances are compatible with fusion of the molar tooth germ with a buccal supernumerary tooth germ, while others may be additional cusps arising from additional enamel knots.

The presence of both parastyles and protostylids in both members of one of the concordant MZ twin pairs provides some evidence for an association between these two features that may be based on underlying genetic influences. However, this was only one pair, so care is needed in considering the significance of this observation.

Conclusions

This study provides further insights into the frequency of occurrence and degree of expression of the parastyle in several human populations that have not been reported previously. One of the difficulties in scoring parastyles reliably lies in the nature of the system of scoring devised by Katich and Turner, and we have made some suggestions to improve the classification of this feature. It appears that the parastyle, with its varying degrees of expression, results from a complex interaction of genetic, epigenetic, and environmental influences during dental crown development. There may also be a relationship between parastyles and supernumerary teeth that are located buccally to the maxillary molar teeth.

Acknowledgments

The dental casts used in this study are housed in the Murray Barrett Laboratory, Adelaide Dental School, The University of Adelaide. Dr Mohd Khamis collected the Malaysian casts as part of a PhD study with support of a grant from Universiti Sains Malaysia. The Aboriginal casts were collected mainly during the 1950s and 60s at Yuendumu with support from the National Institute of Dental Research Grant DE02034-07 from the National Institute of Dental Research, National Institute of Health, Bethesda, Maryland. The dental casts of twins form part of an ongoing study of dental development and morphology at the Adelaide Dental School supported by the National Health and Medical Research Council (NHMRC) of Australia, the Australian Dental Research Foundation, the Financial markets Foundation for Children and Colgate Oral Care Australia.

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Technical Note: The Definition of New Dental Morphological Variants Related to Malocclusion

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Keywords: dental crowding, midline diastema, canine diastema, overbite, underbite, overjet

ABSTRACT Since the codification of the Arizona State University Dental Anthropology System over 25 years ago, few additional morphological traits have been defined. This work serves to expand the current suite of traits currently collected by biological anthropologists. These traits surround various issues of malocclusion and follow clinical definitions of these traits as well as incorporate observed population variation in character states. These traits include issues of spacing (i.e., diastema and crowding) as well as mandibular and maxillary occlusion (i.e., overbite, underbite). A discussion of the etiology and utility of these traits in bioarchaeological and forensic anthropological research is also given.

The Arizona State University Dental Anthropology System (ASUDAS) has been the standard in defining morphological variants of the teeth for over 25 years (Turner et al., 1991). This publication outlines 36 traits of the dentition as well as rocker jaw, and mandibular and palatine tori. This original work is based on a rich literature defining morphological variation of the teeth (e.g., Dahlberg ,1956; Hanihara ,1961; Harris and Bailit, 1980; Hrdlička ,1921; Morris, 1970; Morris et al., 1978; Scott, 1977; Scott, 1980; Tomes, 1914; Turner ,1970; Turner, 1971). However, since its publication, there have only been a handful of additional traits defined, including the canine mesial ridge (Irish and Morris, 1996), maxillary premolar accessory ridges (Burnett et al., 2010), deciduous morphological variants (Sciulli, 1998), and molar crenulations (Pilloud et al., 2017).

There is room to expand our current understanding of dental morphological variation and to create definitions of additional traits. This paper broadens the current suite of traits and defines variants that may be of interest in bioarchaeological and forensic studies of dental variation that surround issues of malocclusion: canine/midline diastema, dental crowding, and maxillary and mandibular overjet. While these variants are not new to those working with teeth or the human skeleton (e.g., Alt and Türp, 1998; Lasker, 1950), a working definition and scoring system has not yet been created within dental anthropology, with the exception of the midline diastema. Each trait is discussed below and a definition and scoring system is provided.

Diastema

While the midline diastema has been defined in the new volumes by Scott and Irish (2017) and Edgar (2017), their definitions differ as to what exactly constitutes a diastema, they do not offer grades of expression, nor do they incorporate a canine diastema. The definition presented here is based on the definitions provided in these two works as well as several other preceding studies. Further, the incorporation of a canine diastema is included. Therefore, diastemata can occur in the maxillary midline *or* on either side of the mandibular or maxillary canine. The proposed scoring system incorporates both types of diastemata; however, they are discussed separately below.

Midline maxillary diastema

Midline maxillary diastemata have been reported on extensively in the clinical literature (e.g., Chu et al., 2011; Kamath and Arun, 2016; Shashua and Årtun, 1999). Anthropological research on midline maxillary diastemata has identified population, sex, and age differences in the occurrence of this trait (Edgar, 2007; Horowitz, 1970; Lavelle, 1970; McVay and Latta, 1984; Nainar and Gnanasundaram, 1989; Richardson et al., 1973). This discussion focuses on the adult dentition, as midline diastemata can commonly be found in primary and mixed dentition, and can be lost as the

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permanent teeth erupt (Gkantidis et al., 2008).

There are many definitions of diastemata that incorporate various space sizes and grades of expression. In a joint publication by the World Health Organization (WHO) and the International Dental Federation (IDF), a midline diastemata is defined as a space of more than 2.0 mm (Bezroukov et al., 1979). In their new volume on dental morphology, Scott and Irish (2017) define the midline maxillary diastema as any space greater than 0.5 mm (following Lavelle, 1970), and see no need to further define the trait beyond present or absent (based on Irish, 1993). Edgar (2017) also defines midline diastema; however, in her scoring system, 1.0 mm of space is required for presence.

None of the current scoring systems allow for different grades of expression and only focus on presence/absence. However, in their study of nearly 6,000 radiographs, McVay and Latta (1984) found a statistically significant difference in midline diastema size between their sample groups of White, Black, and "Oriental" (sizes defined as <0.49, 0.5-1.49, >1.5 mm). A study of 759 American Black and White children also found there to be size differences, with 19% of Blacks and 10% of Whites having a midline diastema over 2 mm (Horowitz, 1970). Differences in size of midline diastemata were also reported among a sample in South India (Nainar and Gnanasundaram, 1989). It may therefore be useful to separate out grades of expression in global studies of diastema.

Canine diastema

Canine diastemata can occur in the maxilla (sometimes referred to as premaxillary diastema) between the maxillary canine and the lateral incisor (Schultz, 1948), or between the canine and third premolar (Mongtagu, 1989). Canine diastemata also occur on the mandibular canine, again on either side of the tooth. Lavelle's (1970) study of diastemata among 656 individuals found the majority of diastemata were between the maxillary third premolar and canine and the maxillary second incisor and canine. A study by Keene (1963) evaluating midline and canine diastemata (>0.5 mm) among 183 white males found the most common diastema location was between the maxillary canine and the third premolar (even more common than midline diastema). Keene also found that the majority of diastemata were between 1 and 3 mm in size. These studies highlight the potential role of canine diastemata in defining human population variation.

Definition and Scoring System: Diastema

In this proposed system, a diastema is defined as any gap between the teeth with a separation of 0.5 mm or more. Diastemata can be scored in three locations: 1) maxillary central incisors, 2) maxillary canines, and 3) mandibular canines (Figure 1). Among the canines, the separation can occur on *either* side, between the canine and the lateral incisor, or the canine and the third premolar. The current scoring system does not differentiate between the two locations.

0 – absent (< 0.50 mm)
1 – low-grade diastema 0.5-1.49 mm
2 – high-grade diastema ≥1.5 mm

Affected teeth: maxillary central incisors, mandibular canine, maxillary canine

Figure 1. Individual with a midline maxillary diastema (score of 1), and a canine diastema (score of 1) (photo courtesy of G. Richard Scott).

Dental Crowding and Occlusion

In this discussion, it is important to define occlusion and note the ideal model of occlusion to identify deviations from normal (i.e., malocclusions). Occlusion "relates to the arrangement of maxillary and mandibular teeth and to the way in which teeth contact" (Türp et al., 2008:446). An ideal form of occlusion occurs when the "skeletal bases of maxilla and mandible are of the correct size relative to each other and the teeth [are] in correct relationship in all three planes of space at rest" (Hassan and Rahimah, 2007:3). The three planes being anteroposterior, vertical, and transverse. Therefore, malocclusion would be any deviation from this norm to include malpositioning of teeth within the dental arcade (i.e., displacement or rotation.), or a disassociation between the dental arches in any of the three planes of direction (Proffit, 1986).

While there are many references regarding the treatment of malocclusion in the clinical literature (Angle, 1907; Dahiya et al., 2017; Singhal et al., 2015), there is little consensus on how it is quantified or fully defined (Tang and Wei., 1993). The earliest and still commonly used classification of malocclusion is that offered by Angle (1899). In this work, three types of malocclusion are described, all in relation to the position of the upper and lower first molar. Class I describes normal positions of the molars, and can be further subdivided into Class I - normal and Class I - malocclusion. Class I - malocclusion includes crowding, spacing, and rotations of the anterior teeth, even though the molars may be in normal alignment (Silva and Kang, 2001). Class II is a retrusion of the jaw (i.e., overbite) in which the mandibular teeth occlude posterior to normal (i.e., lower first molar occludes posterior to the upper first molar). Class III is a protrusion of the lower jaw (i.e., underbite) in which the mandibular teeth occlude mesial to normal, typically by the length of one premolar, but may be a larger distance in severe cases.

Since 1899, various other methods have been proposed to quantify malocclusion (e.g., Baume and Maréchaux, 1974; Björk et al., 1964; Little, 1975). In the late 1960's, research out of the University of Toronto developed the Orthodontic Treatment Priority Index to quantify various types of malocclusion (Grainger, 1967). In the late 1970's, the World Health Organization (WHO) and the International Dental Federation (Fédération Dentaire Internationale– FDI, now called the World Dental Federation) devised a simple method to record malocclusion. This system includes crowding and diastemata as "space conditions". In this system, crowding is defined as present when > 2 mm of space deficiency is observed between the size of the dental arch and the anterior teeth (i.e., incisors, canine, and both premolars). Deviations from normal occlusion in this system include maxillary and mandibular overjets, openbites, and midline shifts, among others (Bezroukov et al., 1979).

As malocclusion can include crowding and malposition of the jaws, the following definitions of malocclusion are offered, generally following the definitions of Angle (1899) and those of the WHO/FDI (Bezroukov et al., 1979).

Definition and Scoring System: Dental Crowding

Dental crowding (Angle's Type I – malocclusion) is defined as the presence of any tooth that deviates from ideal alignment through either rotation or displacement. The system proposed here is based on that described by Van Kirk and Pennell (1959). Rotation and displacement can be categorized into two types: major or minor. Minor rotation is under 45^{o}, where major rotation is defined as 45^{o} or greater from ideal alignment. Minor displacement is under 1.5 mm, and major displacement is 1.5 mm or greater from ideal alignment either labially or lingually (Figure 2). In the original system outlined in Van Kirk and Pennell (1959), each tooth is scored and scores are summed to assess the level of malocclusion. This system could be cum-

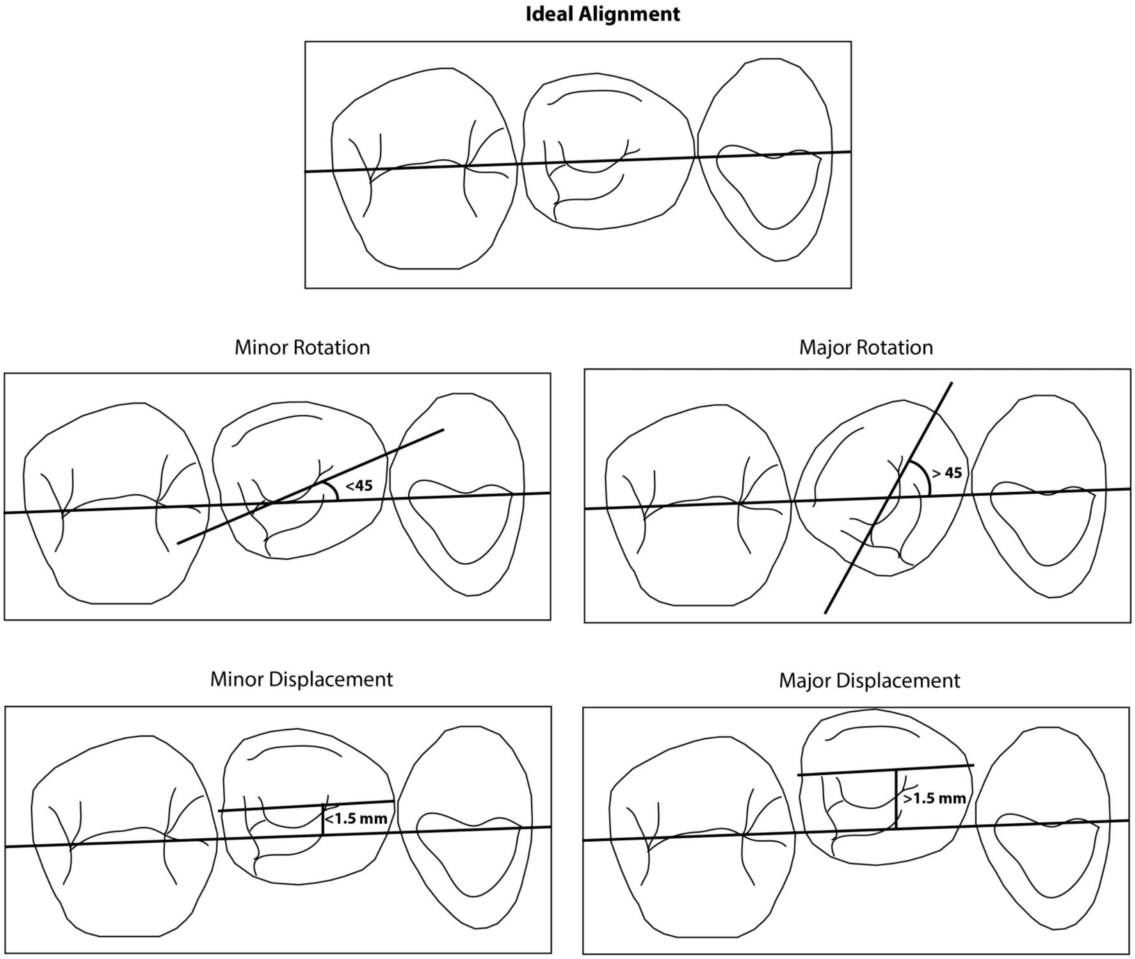

Figure 2. Scoring of rotation and displacement as part of dental crowding for lateral teeth. Based on Van Kirk and Pennell (1959).

bersome in the work of the biological anthropologist and could be impossible when faced with teeth that may be missing ante- or post-mortem. Therefore, the system below is proposed for use in forensic anthropological or bioarchaeological settings.

Crowding is subdivided into incisal and (first and second incisors) and lateral (canine and premolars). The molars are not considered in this system. If all teeth in each class are not present, the level of crowding cannot be scored; allowing for some, but not a lot of missing teeth. If bilateral winging is observed and no other crowding is present in the incisal region, crowding should not be scored (i.e., leave the entry blank for crowding and score winging in its place to avoid redundant data).

Incisal (first and second incisor)

0 – absent – both teeth are in ideal alignment (no rotation and no displacement)
1 – slight – one or both teeth show slight deviations from ideal alignment (rotation between 1^{o} and 44^{o} and/or displacement between 0.1 and 1.4 mm)
2 – moderate – at least one tooth shows major malalignment (rotation ≥ 45^{o} and/or displacement ≥ 1.5 mm), the other may be in ideal alignment or show slight deviation
3 – severe – both teeth show major malalignment (rotation ≥ 45^{o} and/or displacement ≥ 1.5 mm)
Affected areas: mandibular and maxillary incisors

Lateral (canine and third and fourth premolar)

0 – absent – all three teeth are in ideal alignment (no rotation and no displacement)
1 – slight – one or all three teeth show slight deviations from ideal alignment (rotation between 1^{o} and 44^{o} and/or displacement between 0.1 and 1.4 mm)
2 – moderate – at least one tooth shows major malalignment (rotation ≥ 45^{o} and/or displacement ≥ 1.5 mm), the others may be in ideal alignment or show slight deviation
3 – severe – all three teeth show major malalignment (rotation ≥ 45^{o} and/or displacement ≥ 1.5 mm)
Affected areas: mandibular and maxillary canines and premolars

To illustrate this scoring method, two worked examples are presented. In Figure 3, there is a set of mandibular teeth that illustrate crowding and can be scored as follows:

Incisal Right and Left – 0 – there is no rotation or displacement of teeth on the right or left sides
Lateral Left – 2 – the fourth premolar shows slight rotation (< 45^{o}) but shows major displacement (≥ 1.5 mm)
Lateral Right – 2 – the right canine shows minor rotation (< 45^{o}) and the third premolar shows major displacement (≥1.5 mm)

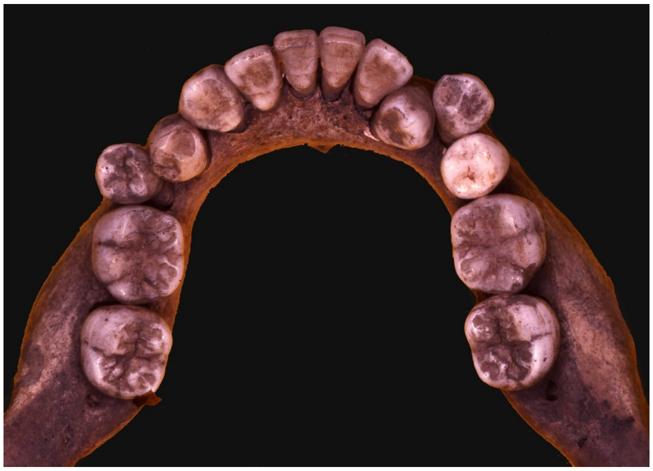

Figure 3. Mandibular teeth that illustrate crowding (photo courtesy of G. Richard Scott and Christy G. Turner, II).

Figure 4 illustrates a set of maxillary teeth with crowding that can be scored as follows:

Incisal Right – 2 – the right second incisor shows major displacement (≥1.5 mm) and the central incisor shows minor rotation (< 45^{o})
Incisal Left – 2 – the left second incisor shows major displacement (≥1.5 mm) and the central incisor shows minor rotation (<45^{o})
Lateral Left and Right – 0 – there is no rotation or displacement of teeth on either side

Figure 4. Maxillary teeth that illustrate crowding (photo courtesy of G. Richard Scott and Christy G. Turner, II).

Discussion

Diastema

There may be a number of causes for a midline diastema, to include a large superior labial frenum, supernumerary teeth, missing teeth, peg teeth, digit sucking, abnormal arch size, muscular imbalances in the oral region (Huang and Creath, 1995), ossifying fibroma of the palate (Kamath and Arun, 2016), or even a tongue piercing (Tabbaa et al., 2010). However, genetics may also play a role. A familial study on the maxillary midline diastema reported the heritability to be 0.32 ± 0.14 among a white sample and 0.04 ±0.16 in a black sample. The researchers concluded that among the white sample there was a stronger genetic basis for midline diastema and that the environment could be playing a larger role in trait expression among the black sample (Gass et al., 2003). While this study reports low heritabilities, many studies have documented population differences in the expression of the trait (Huang and Creath, 1995; Lavelle, 1970; McVay and Latta, 1984; Scott and Irish, 2017), which suggests the utility of the trait in bioarchaeology and forensic anthropology. Further, as several studies have illustrated prevalence rates of canine diastemata in different populations (e.g., Keene, 1963), this trait may have value in biological anthropological studies as well.

Malocclusion

Dental crowding and malocclusion are often discussed in relation to the adoption of agriculture and the introduction of soft foods as part of the masticatory-functional hypothesis (Carlson and Van Gerven, 1977; Corruccini, 1984; Corruccini et al., 1983; Larsen, 2015). In this discussion, malocclusion encompasses two distinct features: malalignment of the teeth (i.e., crowding) and malalignment of the jaws (i.e., overbite and underbite). While these are related conditions of occlusion, they may have separate etiologies. While over- and under-bites have not been traditionally recorded in bioarchaeological or forensic anthropological research, their heritability is well documented in the clinical literature (Chen, 2006; Lee and Goose, 1982; Lundström, 1948; Walker, 1951).

There is, however, considerable debate in the clinical and anthropological literature as to the exact cause of dental crowding. Mossey (1999) argues that while the phenotype is ultimately the result of the environment and genes working together, there is evidence to suggest a strong genetic component to various traits of malocclusion. While there is a documented increase in crowding over human evolution, it is generally the result of a disproportion of the dental arches and the size of the teeth (Proffit, 1986), both of which are largely the result of genes. In fact, a study of tooth size of "North American Caucasians" found that individuals with larger teeth also had more evidence of crowding (Doris et al., 1981). Further, work on Amazonian populations by Normando and colleagues (Normando et al., 2013; Normando et al., 2011) has argued for a strong genetic component to crowding and malocclusions; although, differing opinions exist (see McKeever, 2012). Hughes and colleagues (2001) also documented high heritabilities of spacing (crowding and diastemata) among Australian children.

In a clinical setting, the role of external forces such as resting or chewing pressures (Proffit, 1986), and various skeletal, soft tissue, dento-alveolar factors as well as habits (i.e., thumb or finger sucking) (McDonald and Ireland, 1998) have a documented influence on dental development and malocclusion. While many of these factors that lead to crowding (e.g., size of teeth, supernumerary teeth) may be under genetic control, it is difficult to point to one genetic cause for crowding. As such, many studies have highlighted the role of environment in dental crowding and are largely dismissive of a genetic contribution (Harris and Johnson, 1991; Harris and Smith, 1982; King et al., 1993). Proffit (1986), on the other hand, combines both genetics and environment by arguing that slight crowding is likely related to genetic factors, whereas in cases of severe malocclusion, external factors play a larger role.

While the etiology of dental crowding may not be clear, its occurrence may still be important to study in terms of understanding changes in stresses upon the masticatory system, dental reduction, and changes in diet in the evolutionary past of humans. Until now there has not been a way to quantify or define this trait that could be applicable outside of a clinical setting. The system proposed herein to record dental crowding can be systematically recorded in archaeological and medicolegal settings to evaluate questions of anthropological interest.

Finally, these traits of malocclusion (crowding and maxillary and mandibular overjet) may have relevance as traits that are heritable and could have importance in biological distance analyses as well as studies in the estimation of ancestry within forensic anthropology. A recent study on dental morphological variation collected data on dental crowding among modern samples and found that dental crowding could successfully differentiate populations (Maier, 2017). Moreover, there has already been a substantial amount of work exploring population variation in terms of the three types of malocclusion as defined by Angle: Class I normal, Class I malocclusion (anterior crowding), Class II malocclusion (maxillary overjet), and Class III malocclusion (mandibular overjet). Table 1 outlines the various

TABLE 1. Population variance of malocclusion

Study	Ancestry	n	Class I normal %	Class I malocclusion %	Class II malocclusion %	Class III malocclusion %
(Horowitz 1970)	White	321	53.6	NA	33.6	4.7
	Black	397	76.8	NA	11.4	6.3
(Garner and Butt 1985)	Black American	445	27.0	44.0	16.0	8.7
	Kenyan	505	16.8	51.7	7.9	16.8
(Onyeaso 2004))	Nigerian	663	24.5	50.0	13.7	11.8
(Altemus 1959)	African American	3289	16.48	66.4	12.3	4.9
(Lew et al. 1993)	Chinese	1050	58.8	52.7	21.5	12.6
	White	1000	44.3	61.1	52.2	3.5
(Silva and Kang 2001)	Latino	507	6.5	62.9	21.5	9.1

studies that immediately highlight population differences in the various types of malocclusion, thereby illustrating their relevance to anthropological studies of population variation.

Orthodontic Considerations

Modern orthodontia can impact observations of all of these traits. While braces may seem ubiquitous, they are a relatively new development. In the United States orthodontic work made a marked appearance in the 1950s as the "baby boom" created a larger sample of potential patients. However, the practice did not really take off until the 1970s when the number of qualified orthodontists nearly tripled from the decade before (Asbell, 1990). According to the American Association of Orthodontists (2016), nearly 5,000,000 people were receiving orthodontic care in the United States in 2016, and they estimated that half of the U.S. population could benefit from orthodontic work. In studying traits of malocclusion and the possibility of orthodontic work, it is important to consider various factors that may limit access to treatment. Multiple studies have documented economic and social barriers to receiving orthodontic treatment (Germa et al., 2010; Krey and Hirsch, 2012), as well as ethnic differences in desires for orthodontic treatment (Reichmuth et al., 2005). Additionally, cultural practices and views on beauty can also interfere. For example, in a Nigerian sample of 141 individuals, a study found that 48 (34%) had artificially created a midline diastema for the "enhancement of personal beauty and aesthetic" (Umanah et al., 2015:226). While orthodontic work could erase many of these traits, there are various factors to consider when studying a set of remains such as socioeconomic or social status, ancestry, and antiquity of the remains (i.e., death prior to 1970 is less likely to have had orthodontic care).

Conclusions

These traits of malocclusion all figure prominently in clinical discussions of occlusion and are broadly related to conditions that include spacing issues (i.e., diastema and crowding), and deviations from normal occlusion (i.e., maxillary and mandibular overjet). While the midline diastema has been embraced by the ASUDAS and other dental morphologists, the other traits described herein have not. The reason for this finding is likely related to a lack of understanding of the etiology of these conditions; however, it is argued here that these traits show a degree of genetic heritability and could be relevant to studies of population variation. Yet, the environmental component of these traits of occlusion cannot be ignored and may therefore serve as a means to quantify the degree of malocclusion over human evolution. It is hoped that this definition of a scoring system will generate further discussions of traits of malocclusion and that comparative population studies can be generated to further our understanding of population variation and human evolution.

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BOOK REVIEW

Human Tooth Crown and Root Morphology. By G. Richard Scott and Joel D. Irish. Cambridge: Cambridge University Press. 2017. 332 pp., $49.97 (paperback). ISBN 978-1-107-48073-5.

Dental Morphology for Anthropology: An Illustrated Manual. By Heather J.H. Edgar with illustrations by E. Susanne Daly. New York: Routledge. 2017. 184 pp., $28.37 (paperback). ISBN 978-1-62958512-3.

Dante's Peak and Volcano (1997), Armageddon and Deep Impact (1998) – the universe has an odd tendency toward synchronicity. In 2017, a quarter of a century after the publication of the much photocopied Turner et al. (1991), two different manuals have been published that provide further guidance on how to score human dental morphology – Scott and Irish's "Human Tooth Crown and Root Morphology" (Cambridge), and Edgar's "Dental Morphology for Anthropology" (Routledge).

As lab manuals, both books have a similar structure, with the trait-by-trait guide providing the bulk of the pages. The "bookends" differ somewhat. In Scott and Irish, the introductory sections discuss the history of trait scoring and the ASUDAS, followed by a basic introduction to dental anatomy and terminology. The anatomy section, in particular, is absolutely essential for those unfamiliar with dentition. Without it, using the scoring standards would be difficult. As this comprises only the first nine pages it is not an exhaustive discussion. After 250 pages of the manual itself, Scott and Irish concludes with a ten page chapter on scoring concerns and analytical details followed by an appendix of comparative data from the Turner archives. These data are invaluable and should not be overlooked in assessing the merits of this book. Scott's efforts to organize these archives should be commended and will greatly impact the field in the future. A well-known standard analytical complications are also summarized: sexual dimorphism, inter-trait correlation, breakpoints and tabulation methods, wear and age effects, observer error, and a short discussion of the MMD. A sample data sheet is also provided.

Edgar's bookends have a different focus. Instead of discussing the history of the field and dental anatomy, Edgar details distinct problem orientations at different scales of analysis. Challenges of trait scoring are outlined, but with less detail than in Scott and Irish. However, Edgar provides a more thorough overview of analytical methods, which results from her emphasis on global through individual scales of analysis that require more than MMD statistics. After 120 pages of the trait manual, Edgar's book closes with a sample data sheet, reference pages, and a glossary. Neither book is exhaustive in its treatment of the topics presented in their introductory and closing sections, but these overviews do serve to point the reader in the right direction.

Although required for context, few readers will buy the books for these extras. The value of both is in the lab manual section and its utility for trait scoring. Both use a standard structure in their tour of traits. Edgar adopts a grid system with a "two pages per trait" format that crosses the fold. For each trait the following is provided: trait name, ASUDAS plaque (if applicable), a visible guide indicating where on the tooth to observe/score the trait, and a grade-by-grade description and visualization of the different scores. For most traits, each expression grade is visually represented by a drawing with two or more images of actual teeth from varying angles. The ASUDAS plaque is not shown for each trait. The use of a grid makes sense for the purposes of standardization, but with two rows of five boxes, some trait presentations look odd due to the large amount of blank space on the page. However, the attempt to standardize the presentation is commendable and was clearly designed with an eye toward direct use in data collection. My main critique of the Edgar volume is that the images should be larger, and the drawings are really the best illustrations of the morphological variation presented.

Scott and Irish use a different approach. Individual traits receive differing levels of attention rather than a standard two-page treatment, however, a standard set of information is presented for each character: teeth observed, key tooth, synonyms, description, classification (the grades), breakpoint, potential observation/scoring complications, geographic variation, and a selected bibliography. For those traits with ASUDAS plaques, a large image is presented with arrows pointing to the key aspect of variation. I note that the plaques are shown larger than 1:1 scale in some cases.

The main difference between the two books is how each defines the goal of a lab manual. Edgar contains less supplemental text and is focused on presenting basic expression grade descriptions and a visual example of each grade. Scott and Irish uses images of ASUDAS plaques to visualize potential ranges of expression, and instead uses images of teeth as examples of specific grades and to highlight potential challenges or present particularly rare examples. My main suggestion for Scott and Irish is to move each grade description and associated reference plaque image to the same page to ensure that there are no orphaned grade descriptions.

The trait lists in each book are similar but not identical. Both books focus on the key list of ASUDAS crown features, with deciduous traits largely omitted. Scott and Irish provide descriptions of root features, while Edgar sets aside a two-page chapter with basic descriptions and a summary table of root variants. Edgar discusses uncommon traits such as lateral incisor mesial bending, tri-cusped maxillary premolars (curiously omitted by Scott and Irish despite being in Turner et al. (1991) where it is listed as extremely rare, Edgar provides two images), supernumerary teeth, and elongated mandibular premolars. Scott and Irish provide discussion of other traits such as marginal ridge tubercles of the maxillary molars and rare traits such as bifurcated hypocone and lateral incisor variants (not mesial bending) as well as ASUDAS features such as rocker jaw, torsomolar angle, and palatine and mandibular tori. In this sense, Scott and Irish remain more faithful to the original Turner et al. article (tricusped premolars, notwithstanding). Neither delves into more obscure anatomy too deeply. This makes sense for Scott and Irish who are more concerned with broad-scale relationships than with random anomalies that may indicate familial relationships. Scott and Irish paginate the traits within the table of contents and also number them sequentially within the text (each page has a running page number with the trait number near the top of the page). Edgar's book does not include a pagination in the table of contents, which makes it more difficult to easily find the information.

In terms of production value, the page size and paper quality are roughly the same (Scott and Irish is slightly larger than the standard 6x9 inch page size). Scott and Irish is spiral bound, which makes it easy to use because all pages open completely and the book can lay flat on the table. This is important when collecting data. Edgar's book is traditionally bound with hard boards, which makes it more difficult to see the pages without breaking the spine. The picture quality is also sharper in Scott and Irish's book. The figures are almost all photographs, whereas Edgar's book includes a mix of drawings and photographs. An important difference here is the size of the images. Scott and Irish use large format images (roughly half page) that are excellently reproduced by Cambridge. Some of Edgar's images are small and difficult to see as Routledge's image reproductions were often grainy and less than optimal. Using Hillson-Fitzgerald calipers I measured the images provided for incisor double shoveling and came up with 126.68 x 84.88 mm for Scott and Irish and 21.91 x 20.26 mm for Edgar. I initially thought Edgar was trying to show the features at a 1:1 scale, but this was not the case.

The sixty-four thousand dollar question – do these manuals replace the Turner et al. article? Probably. But there are some important considerations, and these relate to the trait descriptions provided. Neither are exactly faithful to the terminology from the 1991 article, which begs the question of whether simply copying the same trait descriptions would violate copyright (I suspect the word count is beyond fair use). This is somewhat unfortunate because there is the potential for observer error to occur. An as example, for cusp 6 Edgar specifies numerically how much larger the cusp should be for a grade of 5 (a useful addition, though absent from the Turner et al. article). Scott and Irish jettison the 3.5 grade for hypocone (but not metacone), causing a shift in the scores for those that used Turner et al. (a minor point really), but have other slight variances in their grade descriptions (e.g. Carabelli's cusp; collapsing the lower premolar trait into a simple cusp count seems logical). The grade descriptions for tuberculum dentale differ more significantly, as do those of Edgar (both omit the 5- grade, among other wording differences). In the case of winging, Scott and Irish use a completely different system that will require future researchers to be mindful of what they mean when they state that "data were scored using ASUDAS standards." It is, of course, easy enough to convert these scores in most cases, but the publication of these books does require us to be more exact in our methodology write-ups. The important point is that the joint publication of these books reflects continued researcher interest in human dental morphology. Both books help break the sense of stasis the ubiquity of the Turner et al. article created. This was not the intent of its architects, who always intended for trait lists to expand and definitions to be modified and improved, with problematic aspects of the ASUDAS discarded. This really is an exciting time to be a dental anthropologist, and both books will help propel the field in new and exciting directions. Both deserve a space on the shelves of dental anthropologists, along with well-used copies of the Turner et al. chapter.

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ERRATUM

Expression of nonmetric dental traits in Western European Neanderthals [*Dental Anthropology*, 30, 3–15 (2017)]

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The list of authors on the paper, "Expression of nonmetric dental traits in Western European Neanderthals" published in *Dental Anthropology*, Volume 30, Issue 01, 3–15 (2017) should be changed to include Marie-Antoinette de Lumley and Gaël Becam. Frank L'Engle Williams and Gaël Becam should both be listed as corresponding authors. The authors and affiliations of this publication should appear as listed here.

Expression of nonmetric dental traits in Western European Neanderthals

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