ABSTRACT

BADGER, SEAN ROBERT. Tooth Size and Identity: Patterns of Sexual Dimorphism and Developmental Noise in a Modern Thai Sample. (Under the direction of D. Troy Case and Scott Fitzpatrick).

The size of permanent teeth has been shown to aid in sex determination in some populations, and metric asymmetry of the dentition may provide information about differences in environmental factors that influence dental development. For this project, mesiodistal and buccolingual diameters were taken on modern Thai skeletons from the Chiang Mai University anatomical collection. Using binary logistic regression, these measurements were analyzed for sexual dimorphism. Lower canines proved to be the most dimorphic teeth, yielding formulae with up to 69.7% allocation accuracy. Accuracy improved to 93.8% when lower canine measurements were combined with both upper incisors and both lower premolar measurements. Accuracies as high as 100% were achieved when two measurements from seven teeth were regressed, but the sample size fell to a small fraction of the original size. The relatively high latter accuracy percentages suggest potential utility of dental metrics for sex-estimation in this particular population, particularly when combined with other corroborative methods. The pool of applicable individuals is significantly diminished with multiple variables, however, so one may only be able to apply the more accurate regression formulae to a smaller subset of a sample. Asymmetry was also calculated in the sample using both directional and absolute asymmetry scores (DA and AA, respectively). T-tests revealed that none of the crown indices expressed directional asymmetry. All indices displayed statistically significant fluctuating asymmetry except for upper 1st molars. The presence of odontometric asymmetry implies that the average individual from the sample underwent developmental stress during childhood. Although this sample did not display great sexual

dimorphism, the results from the lower canine in combination with those of the upper 1st incisor and premolar might prove useful in sexing young adolescents or other individuals for which morphological methods are inappropriate, particularly if used in combination with other traits.

Tooth Size and Identity: Patterns of Sexual Dimorphism and Developmental Noise in a Modern Thai Sample

by
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DEDICATION

To my Grandpa

BIOGRAPHY

Sean Badger graduated Winston Churchill High School, in Eugene, Oregon, in 2005. He began his college career at San Francisco State University where he studied film production. He transferred to the University of Oregon in 2007, as an anthropology major. At the end of his first school year at Oregon, he attended North Carolina State University's archaeological field school in Carriacou, Grenada directed by Dr. Scott Fitzpatrick. The following June, Sean graduated with a Bachelor of Arts degree in anthropology from the University of Oregon, with a focus on biological anthropology. He began attending North Carolina State University in the fall of 2010.

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CHAPTER 1

Introduction

Physical anthropologists recognize the importance of teeth for understanding human variation. The degree of enamel and dentine hardness can lead to a better rate of preservation than their bones in many situations (Hillson, 1996). The size of those teeth can provide useful information to researchers about the sex of the individual and environmental factors such as nutrition. Human adults express size dimorphism between the sexes throughout the body. Most techniques currently used for distinguishing males from females involve metric and morphological analyses of the pelvis or cranium (Bruzek, 2002; Phenice, 1969; Walker, 2005). However, tooth size has long been known to vary between the sexes (Garn, et al., 1964; Ditch and Rose, 1972; Rösing, 1983), and studies have shown that male average tooth size is greater than average female tooth size in most populations. Therefore, sexual dimorphism in the dentition can be employed for sex-estimation purposes. In some instances, odonometric sex-estimation has exceeded 90% allocation accuracy (Ditch and Rose, 1972; Rösing, 1983).

Human health can also be represented by the state of an individual's dentition. Antemortem tooth loss, caries, calculus, and attrition are all caused by environmental factors that are in one way or another indicative of oral health. Tooth size, itself, reflects childhood nutrition and disease, as the amounts of tissue deposited during dental development are increased with better nutrition (Garn et al., 1965). Stress events during tooth development also lead to asymmetry between dental antimeres, where a tooth on one side is larger than its twin on the opposite side (Scott and Turner II, 1997). Odontometric measurements are, therefore, capable of capturing the details, and significance of, oral health and developmental stress in addition to tooth size differences between males and females.

The degree of sexual dimorphism in teeth, and throughout the body, varies by population (King et al., 1998; Scott and Turner II, 1997). Studies have shown Southeast Asians to have smaller than average bodies that express more sexual dimorphism in long bone breadth than groups in other geographic regions (İşcan et al., 1998; King et al., 1998). Odontometric sexual dimorphism in Southeast Asia has been depicted as limited, however (Garn et al., 1967, Indriati, 2007). In the present study, I demonstrate that tooth size in Southeast Asia is sufficiently sexually dimorphic for reliable sex-estimations to be conducted, and that when multiple tooth measurements are combined into a single equation, results can rival those of the long bones.

I examined the patterns of dental size and tooth loss in a modern sample from the Chiang Mai province of northern Thailand. The data for this analysis included tooth measurements from 202 individuals, with mesiodistal and buccolingual diameters from every tooth type. With these data I created sex-estimation formulae that can be applied to individuals of unknown sex from a similar genetic and environmental background. Since patterns of sexual dimorphism of tooth size are variable between populations, any formulae derived from the sample for this study should only be applied to populations that are similar (in terms of both genetics and environment) (Scott and Turner II, 1997). The ability to identify sex in children was cited by Hillson (1996) as the main success of applied metric variation in human teeth since subadults are not typically sexually dimorphic enough to be sexed using traditional skeletal methods. Subadults with permanent teeth have the same patterns of sexual dimorphism as adults from their population, so the formulae from this study can be applied to adolescents, as well as adults. I have also used the measurement data to analyze fluctuating asymmetry and antemortem tooth loss for this group to provide a better understanding of dental health in present-day Thailand. This study has implications for understanding Thai tooth size variation which is useful for examining health and development in this part of Southeast Asia.

CHAPTER 2

Background

Dental size variation: genetic and environmental factors

Anthropologists attempting to understand why tooth size varies between populations must consider genetic and environmental factors relating to an individual's tooth development and ontogeny. The links between tooth crown size and genes have been examined by several researchers over the past decades (Alvesalo and Varrela, 1991; Dempsey and Townsend, 2001; Garn et al., 1965, 1967; Saunders et al., 2007). Many scholars have sought to understand the specific roles of X versus Y chromosomes in explaining dental sexual dimorphism (Garn et al.,1965; Moss and Moss-Salentijn, 1977). Other studies were interested in the level at which teeth were influenced by the environment and/or natural selection and to what degree (Dempsey and Townsend, 2001; Garn et al., 1965). In general, these researchers have added to the collective understanding of what the observable variation in tooth size in any given sample means.

Moss and Moss-Salentijn (1977) explored the processes that lead to sexual size dimorphism in human canines. They examined measurements of tooth diameters as well as the thickness of dentine and enamel for each surface (mesial, distal, buccal, and lingual). Canines, as they explained, were the most sexually dimorphic in terms of absolute crown size, male teeth being larger than female teeth by 3%-9%. This was the explanation they gave for the much greater coefficient of variation (V) present in a pooled-sex sample of canine dentine and enamel measurements. V is the ratio of the standard deviation to the mean, so larger results equate to larger standard deviations, and thus, greater variability. The coefficient of variation is greatest in mesial enamel, always greater in enamel than dentine, and tends to be greater in maxillary teeth than mandibular teeth. Canines, however, always have the greatest V (29-69.4% compared to 6.7-16.6%), which translates to the greatest size difference between the sexes. According to the authors, such sex differences seem to be linked to the respective functions of the X and Y chromosomes during amelogenesis (enamel deposition). Males have a longer (in absolute terms) period of amelogenesis than females (~70 days longer) (Fanning, 1961, 1971) which likely contributes to the size differential (approximately 4-8 µm/day).

The respective effects of the X and Y chromosomes during dental development can shed light on why teeth exhibit sexual dimorphism. Not only do males have a longer period in which amelogenin, the substance that forms tooth enamel, is synthesized, but males also develop greater amounts of dentine than females and that difference is likewise linked to chromosome idiosyncrasies, as noted by Alvesalo and Varrela (1991). They reported that the X chromosome exerts its primary control over enamel, but Y chromosomes promote both enamel and dentine growth to a greater extent. The degree to which this impacts size dimorphism was explored by Saunders et al. (2007) who analyzed longitudinal thin tooth sections to determine the relative sexual dimorphism ratios of enamel to dentine and pulp chambers. Their sample consisted of 45 known sex/age-at-death individuals from 19th century (1821-1874) St. Thomas Anglican Church in Ontario, Canada. They advocated destructive analysis, when possible, for the increase in accuracy over measures such as CT and radiography. Their results showed that male canines and premolars have more dentine than female teeth as well as a greater dentine-to-enamel ratio. However, females have a greater ratio of enamel to crown size than males for these teeth. Females had relatively, but not absolutely, more enamel than males, which fits with the model in which males have larger overall tooth crowns than females in general. X and Y chromosomes, therefore, have different respective influences on dental tissue proportions.

Research suggests that there is a strong link between genetics and tooth size patterns among individuals and groups, but questions still remain as to the level of environmental influence. A study by Garn et al. (1965) focused on comparative dental development between siblings and parent/child pairings to determine the extent to which X/Y chromosomes exert control over tooth size compared with environmental stimuli. The researchers recognized that there exists variability in development between regions, and that this can lead to varying patterns of tooth sizes both within and between groups. They also noted that these differences highlight the importance of genetics in controlling tooth development, as both the world's largest and smallest teeth are found in hunter/gatherer groups (Campbell, 1925; Moorees, 1957). They sought, however, to understand how susceptible teeth were to the environmental factors that influenced long bone growth between disparate groups. Their (1965) study drew from the Fels longitudinal data collected from living participants in Southwest Ohio who were of northwestern European ancestry. The tooth measurements were MD crown diameters taken from casts. They also measured fat content by way of chest radiographs (fat shadows at the 10th rib). Because children with greater body fat tend to grow taller earlier than their peers, Garn et al. (1965) sought to discover the extent to which this was also true for dental development. They found that body fat was positively correlated with dental developmental status in children, where bigger individuals are also more dentally developed. The same was true for taller children in general, as well as girls who reached menarche earlier than average (although there do exist interactions between such conditions and body fat content). While there is a more advanced degree of dental development in such children, it is only by a slight, though still statistically significant, amount. Long bones, by comparison, show three times the response to nutritional differences as teeth for this sample. The long bone development area most strongly correlated with dental development, in terms of responsiveness to nutrition, was the proximal tibial epiphysis.

Garn et al. (1965) also delved into how strongly genetics factored into dental size variation in families. They measured the tooth sizes (MD coronal diameters) of sibling and parent-child pairs to determine how much odontometric variability existed between specific types of pairs. Monozygotic (MZ) twin pairs show a 0.90 correlation in dental development (calcification, movement, and completion). When compared with right-left side correlations within individuals which do not exceed 0.95, it becomes clear that 0.90 is very near to the maximum correlation between individuals. Lower I2, P2 and M3 had the least correspondence between MZ twins. Overall, sibling pairs showed a 0.30 correlation in tooth development. Sister-sister pairs were the strongest at 0.64, brother-brother pairs were 0.38, and brother-sister pairs were the least correlated at 0.21. Garn et al. (1965) suggested that this likely reflects the chromosomal redundancy inherent in XX and not XY. The researchers indicated that tooth size dimorphism is more strongly expressed within families than between them, and that the more genetically similar the members of a group are, the more evident sexual dimorphism will be.

Another study of families by Dempsey and Townsend (2001) was designed to better understand the genetic/environmental factors that are responsible for tooth size variation. They determined, in accordance with previous studies, that additive genetic effects—the variation caused by having different genes—are the primary contributors to permanent dental crown size in humans. Maxillary 1st molars proved to be the most influenced by common environmental factors, which is consistent with their period of calcification that begins around birth, as birth serves as an environmental stress event. Some teeth (the canines and 1st premolars) were significantly affected by non-additive genetic factors, i.e. the variation caused by the interaction of genes. Non-additive variation is generally associated with genes relating to selective fitness, so the presence of non-additve genetic effects in the above teeth implies that their sizes are, or at some point were, previously under selective pressures (Fisher, 1958; Kacser and Burns, 1981; Dean et al., 1988 sensu Dempsey and Townsend, 2001). This fits with Garn et al. (1967)'s explanation that canine size dimorphism is an ancestral trait in humans. Although females can have larger canines than males if they come from families with larger and smaller teeth, respectively, male canines tend to be larger on average across populations—a pattern that Garn et al. (1965) suggested hints at the involvement of Y chromosome-specific dental coding. This also supports the conclusions of Alvesalo and Varrela (1991), above.

How genetic factors influence sexual dimorphism was another subject investigated by Garn et al. (1967). They examined brother-sister pairings to discover how tooth size covaries between siblings. The study showed a dimorphism correlation of 0.345 for dental sexual dimorphism in brother-sister pairings. Using this information, they concluded that as one brother-sister pairing exhibited strong sexual dimorphism, other such pairings from the same family line showed similar dimorphism. The findings lend credence to a genetic influence on sexual dimorphism in human teeth. Evidence also suggests the existence of a canine “developmental field” where the teeth adjacent to the canines have higher levels of sexual dimorphism than those at greater distance (Garn et al., 1967). This may imply the evolutionary significance of these teeth among males, corroborated by a strong degree of canine dimorphism shared between humans and other primates. Some species of apes have a sex difference in mesiodistal crown diameters of 50 percent or more (Garn et al., 1967). While human canines are less sexually dimorphic than those of great apes, there seems to be an evolutionary trend for human and nonhuman primate males to have larger canines than females.

Evolutionary trends also exist between tooth and body size. Body weight, derived from fat, muscle, and bone, has been significantly correlated with tooth size (Anderson et al., 1977). Lavelle (1977) noted that such correlations were stronger in apes and ancient humans than in modern humans. The modern shift was said to be due to a reduced selection pressure to maintain relative tooth size. Body size and tooth size are minimally correlated in humans (Hillson, 1996). The levels of dimorphism are more strongly linked, however. Garn et al. (1967) claimed that sexual dimorphism in dental size expresses a statistically significant link with body size dimorphism in brother-sister pairs, so the extent to which males are larger than their female counterparts in body size will be reflected in the amount of tooth size difference.

Tooth morphology varies by population along with tooth size. Wide, shovel-shaped incisors or accessory cusps of molars may increase measurements from certain individuals. Such variation can even be seen within a relatively small geographic area. In Thailand, for instance, certain populations can be seen to have Northeast Asian dental features (Sinodonty) while other populations have dental features more in line with the majority of Southeast Asia (Sundadonty) (Manabe et al., 1997). These differences were evident between two types of agriculturalists: those in flatlands and those in the mountains. The flatlanders had the Sundadont characteristics, implying that the plains were colonized before the arrival of the mountain-dwellers with Sinodont characteristics (Manabe et al., 1997). The variations in tooth shape between groups helps explain why different patterns of sexual dimorphism exist across different populations.

Due to the above-discussed genetic and environmental peculiarities, teeth erupt at different ages depending on the population. Though permanent tooth crowns begin to develop within the first few years of an individual's life, these teeth do not begin to erupt until several years later. Ubelaker (1989) described patterns of dental eruption among Native American populations. Permanent canines erupted on average between 10 and 11 years of age for mandibular canines, and between 11 and 12 years for maxillary canines. Mandibular permanent molars erupted between 5 and 7 years for M1 and 11 to 13 years for M2 on average. Permanent upper incisors 1 and 2 erupted around 7 to 9 years. Canines, upper incisors, and lower molars are the most dimorphic teeth according to Garn et al. (1967) and

Rösing (1983). As such, they set the lower limit of ages of juveniles with sexually dimorphic permanent teeth. Individuals would need to be at least 5 years of age just to have the 1st molars present.

The genetically-influenced nature of sexual dimorphism patterns suggest that the teeth most likely to yield accurate sex-estimation formulae should be based on that population's most dimorphic teeth. Because it is known that dental development varies across populations (Garn et al., 1965; 1967), and that this creates different sexual dimorphism patterns from one group to another, population-specific patterns are vital to a viable study of a particular region. Populations in Southeast Asia have relatively high sexual dimorphism in maxillary incisors (I1:4.9%, I2:4.5%) in relation to their canines, as represented by Javanese populations (Garn et al., 1967). In comparison, mandibular M1 was 2.7% dimorphic, while the mandibular canine was 5.9% dimorphic. Incisors erupt shortly after M1 (approximately 1 to 2 years later), making them similarly useful in sexing juvenile individuals (Ubelaker, 1989).

Odontometric sex-estimation studies

Researchers over the last several decades have attempted to determine just how viable odontometric data could be as a tool for sex-estimation purposes. Such research serves anthropological disciplines such as bioarchaeology and forensics, both of which frequently employ sex-estimation techniques on skeletal material found in the field. Traditional morphological assessments of the pelvis and skull are highly accurate, but require the presence and integrity of those bones. Teeth, if they can be reliably used to estimate sex, would present a useful tool to use in conjunction with morphological techniques when some or all of the morphological features are not in a condition to be assessed.

Permanent dentition in humans exhibits sexual dimorphism in several ways. Enamel thickness, absolute tooth crown size, root lengths, dentine thickness, and rate of enamel deposition are all factors which potentially vary between sexes. Moss and Moss-Salentijn (1977) found that a longer period of amelogenesis—the process of enamel formation—in males was the cause of size differences of tooth crowns between the sexes, though they could not determine whether dimorphism patterns were due to genetic or environmental factors. Amelogenesis occurs over a longer period of time on male teeth than those of females, leading to larger crown sizes. An important aspect of sexual dimorphism in crown size is that such measurements can be taken while teeth remain in their sockets. This allows the researcher to know with certainty that the teeth belong to a particular individual. It also has the added benefit of allowing for anthropometric research from casts, should a study require it.

Tooth crown diameters are the most common measurements for dental dimorphism research. In absolute terms, the most sexually dimorphic teeth are the 1st and 2nd mandibular molars, with differences of 0.52 and 0.45 mm, respectively, based on crown size measurements taken by Garn et al. (1967). These are followed by the maxillary and mandibular canines. The canines demonstrate the most sexual dimorphism by percentage, however, at up to 7.3%. Canines are also useful for bioarchaeological studies because they do not accrue wear as quickly or drastically as molars (Hillson, 1996). Garn et al. (1967; 1977; 1979), for example, were able to correctly sex up to 87% of individuals in their study using permanent tooth crown diameters. Ditch and Rose (1972) and Rösing (1983) correctly classified 90% of adult cases by testing dental discrimination from diametric crown measurements. Permanent tooth crowns are, therefore, useful for determining sex in adults.

Typically, only adults will express sufficient cranial or pelvic sexual dimorphism to allow for traditional techniques to be employed, but teeth have the potential to be of use for estimating sex in subadults. Studies have shown that techniques involving skeletal morphology are only reliable for individuals considered to be physiologically adult (individuals may be considered adult as early as 16 years of age at death) (Saunders, 1992; Tayles, 1999). Teeth, however, achieve their adult crown size before they erupt in late childhood/early adolescence (Ferembach et al., 1980), so population-specific patterns of odontometric sexual dimorphism should apply equally well to all individuals in a population whose permanent teeth have erupted. Rösing (1983) used this approach to identify sex in juvenile skeletons from an archaeological context. He examined a sample of 28 male and 27 female adults from the Egyptian cemetery Qubbet-al-Hawa to determine patterns of sexual dimorphism. Rösing took four measurements from each tooth: mesiodistal (MD) and buccolingual (BL) diameters, crown height, and root height. He determined that root height was a poor indicator of sex, and omitted the measurements from further analyses. He confirmed that the canines show the most dimorphism, with both upper incisors as the next best. His best discriminant functions for sexing were 97% accurate for adults. His formulae were applied to the children from the sample population, identifying 44 as male and 17 as female. Because they lacked any prior sex assignments, Rösing was unable to test the accuracy of these identifications. Sex-estimations in bioarchaeology are by their very nature imperfect, but still provide a basis for further research.

Deciduous teeth display sexual dimorphism as well, though less so than permanent teeth. Adler and Donlon (2010), using metric crown traits of canines and molars, only achieved 70.2% to 74.8% accuracy in sex determination. Studies using deciduous dentition are also problematic in that any population-specific pattern would require knowing the sexes of the individuals on which the pattern was based. Therefore, any study attempting to identify the sexes of prehistoric individuals would not be able to use deciduous teeth. Measurements need not be only taken on the lengths and widths of whole tooth crowns. Adler and Donlon (2010) measured molar trigon (the main triangle of mesial cusps on each molar) and talon (the ancillary, distal molar cusp[s]) portions of deciduous teeth. They showed the greatest sexual dimorphism in the mesiodistal diameter of the trigon at 11.11%. Hypothetically, each cusp may have different levels of dimorphism which would be overlooked by performing only measures of crown diameter. Should a similar study be performed on permanent teeth, the accuracy of molars in determining sex might increase. Such a study could include both trigon/talon measurements as well as measurements of each cusp, individually. Certain cusps may be more sexually dimorphic than others, even within the trigon/talon portions.

Fluctuating asymmetry in human teeth

Human morphology exhibits bilateral asymmetry in many ways. Long bones frequently have greater length and robusticity on one side over the other. For bones, this is usually associated with behavior, where activity promotes robusticity, particularly during the period when a child is growing (Lazenby, 2002; Steele, 2000 sensu Auerbach and Ruff, 2006). Such patterns are known as ‘directional asymmetry’ as a population will tend to have larger right arms than left arms, for instance. Teeth, which have antimeres on either side of the body, are highly symmetrical; much more so than long bones, as they are not influenced by activity in the same way. The differences that do exist between dental antimeres of the same individual occur because of what is known as ‘developmental noise’—episodes of stress such as disease or malnutrition that may intervene in an individual’s growth and development (Scott and Turner, 1997). These incidents promote what is known as ‘fluctuating asymmetry,’ (FA) which does not favor one side over another across a population.

Kieser and Groeneveld (1988) described how FA is correlated with a lower standard of living, by comparing indigenous and European South Africans. They asserted that the differences in living conditions are clearly discernible by the high infant mortality and childhood morbidity rates among the indigenous population, which are much higher than for those of European descent, and are much more frequently related to infection and malnutrition. They also charted the asymmetry profiles of European and indigenous South Africans and compared them to the Lengua of Paraguay, a “preliterate” society used as an example of a population exposed to regular nutritional stress and parasitic diseases. The profiles revealed that premolars, 2nd upper incisors, and 2nd molars were the most odontometrically asymmetric teeth for all three groups, but that indigenous South Africans had much more asymmetry than the Europeans, who themselves expressed only marginally less asymmetry than the Lengua. These results imply that severity of stress may be mitigated to an extent by genetic factors, but that environmental conditions still ultimately determine the magnitude of asymmetry present in a given population.

The relationship between odontometric FA and stress was explored by Hoover et al. (2005) who compared numbers of linear enamel hypoplasia (LEH) episodes with severity of metric asymmetry in a population from the Isola Sacra necropolis of Imperial Rome. They found few significant links, however, possibly because LEH is correlated with nutrition while FA requires greater systemic stress over a longer period (Hoover et al., 2005). Another problem that may have hampered this project was that, unlike with LEH, there appears to be a relationship between FA and hereditary conditions. Some kin groups experience similar patterns of FA between individuals, apparently stemming from genetic anomalies that lead to defective enamel development (Hart et al., 2000, 2002, 2003a sensu Hoover et al., 2005).

FA can be expressed metrically and morphologically. Traits such as number of molar cusps and groove pattern, while they are symmetrical to a high degree, can show asymmetry in about 5% of cases (Garn et al., 1966). Studies by Garn et al. (1965, 1966) suggest XX chromosomal pairings cause sister-sister pairings to exhibit less odontometric variability than either brother-brother or brother-sister pairings. However, males and females do not appear to have significantly different FA magnitudes, as revealed by the Kieser and Groenenveld (1988) study. This is evidence against the hypothesis posited by Nichol et al., (1984) that males and females are differently able to buffer against intrauterine asymmetrogenic factors.

AMTL in Southeast Asia

AMTL , or ‘antemortem tooth loss,’ refers to any loss or removal of permanent teeth before an individual has died, whether intentional or pathological. Such tooth loss is common in any population, but with differences in causality (Lukacs, 2007). Many cultures surgically remove teeth to combat malocclusion or impacted growth. Teeth are also frequently lost or pulled because of periodontal abscessing—destruction of the bone holding the tooth in place—resulting from infection (Hillson, 1996). Caries are frequently associated with AMTL as demineralized teeth can expose the pulp chamber and gingiva to abscess-causing pathogens (Lukacs, 2007).

In many groups, females have been proven to have significantly more caries than males. Lukacs (2011) suggested that this disparity between the sexes, which in turn leads to differences in AMTL rates, may be linked to the division of labor as well as hormone differences. Hormones produced by pregnant women can change their saliva to be more acidic. Tasks allocated to females, such as preparing food and being exposed to it for much of the day—especially of sticky, starchy foods—may also contribute to a greater propensity to develop caries.

Tayles et al. (2000) linked modern Thai caries rates with a subsistence focus on rice as well as a relatively recent shift toward sugars and other carbohydrates. The region is also home to many sugary and sticky fruits such as bananas and palm sugar that are highly cariogenic. This may account for what AMTL is present in Southeast Asia today, although oral hygiene practices and one’s ability to afford dental care would likely have the greatest impact on whether or not modern individuals would retain their teeth throughout their lives.

CHAPTER 3

Materials & Methods

The subjects of this study were mandibular and maxillary teeth from 202 individuals belonging to the Chiang Mai University Skeletal Collection, Chiang Mai Thailand (henceforth referred to as the Chiang Mai sample). Access to the collection was kindly granted by curator Prof. Pasuk Mahakkanukrauh, MD. The collection contains over 300 individuals from modern northern Thailand, and more individuals are being added each year. The bones were stored in sealed plastic containers that prevented environmental damage, but the bones were in variable states of cleanliness. Skeletons were separated by individual and organized by year of death. At the time of data collection, the years of death ranged from 2003 to 2010. Measurements were taken on every individual under 70 years at death (and some individuals over that age to improve the sample size). Males make up the majority of the collection. The sample used for this study consisted of 126 males and 76 females. The mean age-at-death for females from the sample was 60.2, with a range of 78 years (min 15, max 93). Males had a mean age of 58.9, with a range of 74 years (min 22, max 96).

Data collection

Measurements to two decimal places were collected on every buccolingual (BL) and mesiodistal (MD) diameter for teeth that were present on individuals below 70 years at death using a pair of Hillson-Fitzgerald digital dental calipers. Twenty-three non-edentulous individuals over 70 years were later included, with an emphasis on females (17 females to 6 males), to reduce the difference in group size between the sexes and improve the overall sample size. The diameter measurements were taken parallel to the dental cervix at the widest aspect of each tooth in the respective plane. For each anterior tooth, the tuberculum was included in BL diameter measurements, as it contributed to the greatest crown width. In this paper, teeth are referred to by a three or four character code: arcade (U/L), side (L/R), type (I/C/P/M), and number (1/2/3). A lower right second premolar would therefore be designated "LRP2," while an upper left canine would be "ULC."

When certain teeth were not measureable, codes were used to indicate the reason for a missing measurement. If the tooth was present but displayed either wear or breakage (or a combination thereof) that was sufficiently severe to prevent measurement, a “w” was recorded. If caries activity prevented measurement, a “c” was recorded. A “w/c” was recorded if damage to the tooth was a combination of wear/breakage and caries, or if the cause could not be distinguished. A recurring phenomenon in the Chiang Mai collection that precipitated the use of “w/c” labels was a stepped pattern of wear expressed along the labial cement-enamel junctions (CEJs) of the anterior teeth in multiple individuals (see Figures 3 and 4). Because these characteristics were not the primary focus of the study, and because time was a factor, a rigorous approach was not followed for the collection of these wear data.

A more systematic method was employed for logging the antemortem tooth loss/postmortem tooth loss (AMTL/PMTL) status of missing teeth. Because the skulls were not wrapped or kept in separate containers, teeth frequently fell out of their sockets during storage and movement. The defleshing process at the university also allowed for PMTL, as bodies were buried in a shallow pit to decompose. Those teeth that were present in an individual's storage container after curation and that were a match for the rest of the individual (size and color match, correct numbers of teeth, fitting back into their sockets, etc.) were measured as usual. When no teeth could be found that matched an empty socket, a label of "p" for PMTL was recorded. If a socket had been partially or completely healed over then a label of "a" for AMTL was recorded. Because AMTL can provide insight into the health and behavior of a population, these "a" recordings were analyzed for patterns between specific teeth and the two sexes.

Lastly, the size of talon vs. trigon for each upper molar was measured (see Figures 5 and 6), to assess whether the ratio was subject to any significant sexual dimorphism. Analyses of these ratios are limited by the small number of suitable molars from the sample. As few as 10 third molars and as many 31 second molars comprise the range of available talon/trigon measurements. Such measurements from permanent teeth may represent stronger sexual dimorphism than the deciduous measurements used by Adler and Donlon (2010) that had relatively low sexing accuracy.

Statistical procedures

The data were verified by examining boxplots and z-scores in IBM SPSS (v. 19). Any z-scores of 3 or greater were deleted, as the greatest number of measurements coming from each sex for any of the variables was 88 and measurements that are 3 standard deviations from the mean are unlikely with a sample size smaller than n=100. The remaining measurements were displayed in boxplots, and those that were marked "*" were examined. If they did not fall within the range of the opposite sex, or were close enough to the other measurements to seem realistic, they were retained. The cleaned data set was then used for all future statistical analyses. The final number of measurements in this data set is 9257 diameters and 716 trigon/talon measurements.

Human error is a major obstacle in odontometrics, as fractions of millimeters can have a substantial impact on statistical output. Intra-observer error was assessed using technical error of measurement (TEM) calculations, as described by Norton and Old (2000). TEM is designed to assess the degree of human error that occurred between two or more sets of like measurements on like samples. In order to justify the use of a set of measurements, the TEM must be calculated for each type of measurement. Those measurements with high TEMs must be disregarded and excluded from all regressions and other statistical analyses. In this study, 10 individuals were measured twice by the same observer, so only intra-observer error is evaluated.

Sex-estimation equations

Binary logistic regression analysis was performed on each measurement and tooth for the purpose of analyzing sexual dimorphism in the dental measurements[1]. Buccolingual (BL)

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[1] Traditionally in anthropology, discriminant function analysis (DFA) has been employed for distinguishing between binary outcomes (such as male vs. female). Garn et al. (1977) were able to use DFA to classify sex correctly based on tooth size with 86% accuracy. Acharaya et al. (2010) explained, however, that logistic regression analysis (LRA) may be

and mesiodistal (MD) diameters were regressed separately as well as combined with each other, creating three regression models per tooth, with varying allocation accuracies. Including both measurements from a single tooth as covariates may increase the sexing accuracy from single-variable regressions without suffering much of a loss in number of applicable individuals. There were 72 regressions in this first series. Regression results of MD and BL diameters were compared against each other and those of the combined measurements.

The most accurate predictors were then combined to create formulae with even better sex-prediction accuracy. The variables chosen to represent the best method of determining sex in similar populations to that of the sample should not only yield the highest statistical accuracy from a regression, but also have qualities that make them useful for the field. For instance, teeth that are likely to become separated from a body via taphonomic processes should be excluded. Some teeth are also frequently lost or destroyed during life because of cultural practices, as with the extraction of third molars in many modern societies. For this

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the better choice for odontometrics, due to its greater flexibility in assumptions and ability to achieve high comparable accuracy with DFA when DFA assumptions are met. LRA accommodates both discrete and continuous variables, does not require a normal distribution, a linear relationship, or equal variance within a sample (Norusis, 1990). Acharaya et al.'s (2010) study achieved high sexing accuracy in their sample, with a range of 76%-100% depending on the combination of teeth involved in the regressions. The accuracy range from the same teeth using DFA was only 52%-71%.

reason, few third molars were represented in the sample, so even they were only included in single-tooth regressions, not multi-tooth regressions. The most common teeth in the sample were lower canines (n=144 right, 142 left) and the least common were upper 3rd molars (n=46 right, 37 left). Lower teeth were more common overall than upper teeth in this sample, but this may be due to the method of storage of the skeletons. All crania and mandibles were placed unwrapped in their containers in upright positions, so upper teeth had a propensity to become dislodged and potentially get misplaced while lower teeth more often remained in their sockets. Upper molars (1st and 2nd) were more common than lower molars, likely due to the third root in upper molars that helps to secure the teeth in their respective sockets. Lower canines, described by researchers such as Garn (1965, 1967) as one of the most sexually dimorphic teeth, was incorporated into regressions that involved multiple teeth as covariates to determine whether sexing accuracy would increase without sacrificing too many applicable individuals.

To keep the implementation of a final combined regression formula as feasible as possible, all combinations of teeth came from the same side. The next most common teeth after lower canines were both of the lower premolars followed by the upper 2nd incisors. All of these had at least 100 teeth present in the sample from each side. Variables from these most common teeth were combined in multiple ways and tested for the chance of achieving greatest accuracy while including sufficient numbers of individuals. An attempt was made to trim the unnecessary regressed covariates in order to at once increase accuracy and the pool of applicable individuals by excising those covariates with p-values greater than 0.1. This procedure was performed until all covariates from each previous regression had p-values below 0.1.

To increase the utility of these binary logistic regressions, the individuals measurements, as well as the logits that resulted from the most accurate regression formulae from the single and multi-tooth series, were subjected to receiver operating characteristic (ROC) analysis (only left side single-tooth regression logits were analyzed). This is a technique frequently employed in the medical field for monitoring threshold values when making binary decisions about presence/absence of disease. ROC analysis enables researchers to control the ratios of false positives/negatives to true positives/negatives (Metz, 1978). ROC analysis results in a plot of ratios whose Area Under the Curve (AUC) will increase as measurements are better suited to distinguish true positives from true negatives. Rather than providing the allocation accuracy for a single point in the sample (as with logistic regression), ROC results display a range of data points and the percentage of correct versus incorrect classifications for each point. In sex-estimation, positives may indicate males and negatives females, or vice-versa depending on how the data are entered. ROC analysis can be conducted on single measurements, but with regressions that include multiple measurements, the resulting logits must be compared, as they test the viability of regression equations. One must ensure, however, that only individuals for whom you have every measurement from which the logits are derived are incorporated into the ROC curve to avoid misinterpretation of the output.

Asymmetry analysis

Tooth measurements from the sample were also indexed and analyzed to assess bilateral asymmetry. Tooth indices are, as described by Hillson (1996), a common tool for comparing tooth size that combines MD and BL diameters into a single summarizing number. Indices are the BL diameters divided by the MD diameters. Directional and absolute asymmetry scores were calculated using the method described by Auerbach (2005):

Directional asymmetry (DA)% = ([right – left]/[(left + right)/2])*100

Absolute asymmetry (AA) is the absolute value of DA. The significance of these scores was calculated by means of a one-sample T-test in IBM SPSS (v. 19). DA scores were analyzed first. All teeth that were not shown to display statistically significant directional asymmetry were tested again with their AA scores. Those results revealed the teeth that demonstrated fluctuating asymmetry. Asymmetry patterns were then compared between males and females.

AMTL analysis

Rates of AMTL were compared between the sexes of the sample, to test for potential differences. Only individuals under the age of 75 years at death were included in this comparison, because everyone under that age was recorded, even if they were completely edentulous, whereas those with no teeth present over that age were excluded for the sake of time. For all 32 teeth, the AMTL rate percentages were calculated by dividing the number of teeth coded "a" in each tooth type by the total number of individuals. The differences were tested for statistical significance by way of a one sample T-test in IBM SPSS (v. 19).

AMTL rates were also compared between age groups in an effort to quantify the patterns and extent of tooth loss for this sample. 5-year age categories were established for the sample, and the average number of missing teeth due to AMTL was calculated for each category. Since the individuals over 70 years of age at death in this sample were selected because they had teeth present, the AMTL rates for those age categories were included. These rates do not represent the true average for the age categories, but they can serve as minimums for numbers of teeth lost before death.

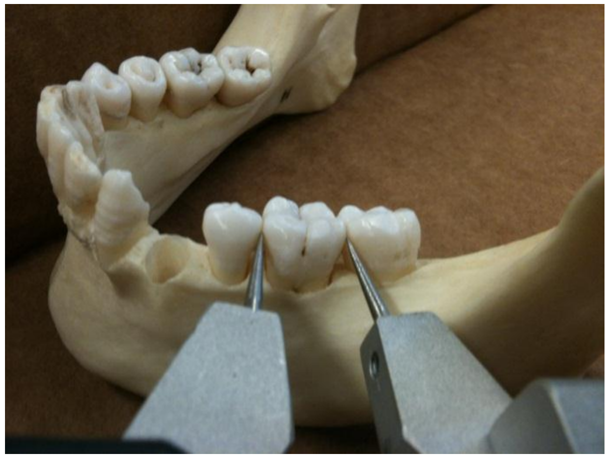

Figure 1. Example of mesiodistal crown diameter measurement (LLM1)

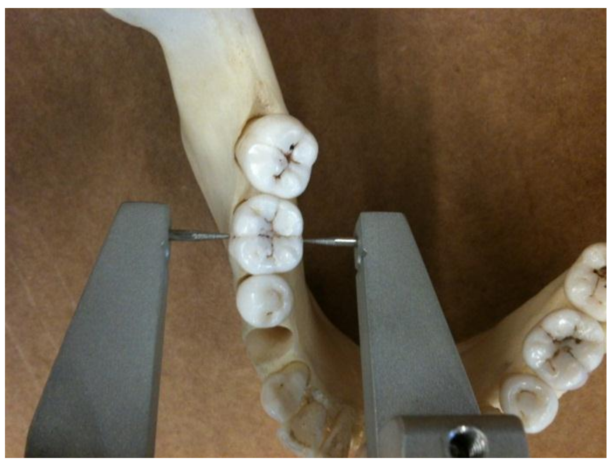

Figure 2. Example of buccolingual crown diameter measurement (LLM1)

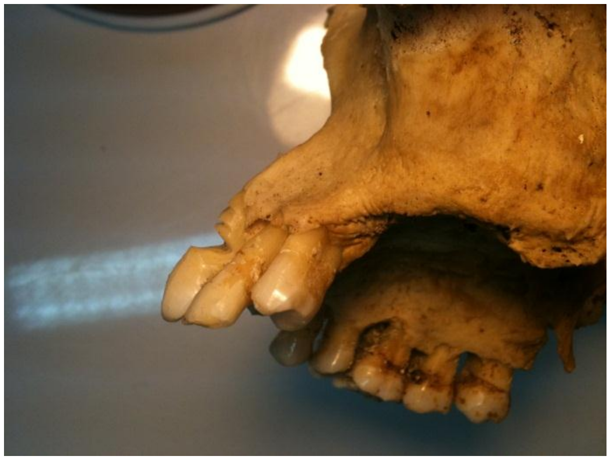

Figure 3. Stepped pattern on teeth in Chiang Mai sample (side view)

Figure 4. Stepped pattern on teeth in Chiang Mai sample (front view)

Figure 5. Example of molar trigon measurement (ULM2)

Figure 6. Example of molar talon measurement (ULM2)

CHAPTER 4

Results

Intra-observer Error assessment

The results of the TEM test are in Appendix D. All relative TEM percentages were below 3% except for upper left 2nd premolars, which were 7-8%. The talon measurements of the second molars were also an exception, with a dramatically high 14 to 20% relative TEM, limiting their statistical usefulness.

Binary logistic regression

In the primary (single-tooth) series of regressions, an equation was created for each tooth (as MD, BL, and the combination of both). The resulting formulae yielded accuracies in the 48.9% (URI1 MD) to 81.8% (URM3 MD) range (see Table 1). Accuracies near 50% equate to random assignment, and therefore represent no discriminatory ability. These percentages refer to those individuals whose sexes were correctly predicted using the respective logit equations. The individual measurements that produced formulae with the highest accuracies (70s and high 60s) were combined to find the best balance of sample size and sexing accuracy. The most accurate of the single-tooth regressions were those of the 3rd molars, but because of the small number of individuals in this sample who had these teeth present, they were not included as partial regression coefficients in later multi-tooth Table 1.

regressions. ULM3 BL yielded a fairly high accuracy of 75%, but only 23 males and 13 females were incorporated into this ULM3 BL regression. 3rd molars were especially underrepresented for females in this sample.

The patterns of accuracy between MD, BL, and the combination of these measurements varied between teeth. The ULI1 BL regression had a prediction accuracy of 66.7% whereas the MD accuracy was 58.5%, and BL+MD had an accuracy of 61.7%. ULM1 had a different pattern, where the BL accuracy was was 56%, the MD accuracy was 68.1%, and the combined accuracy was 62.7%. ULP1 and ULP2, however, both showed their highest accuracies when combined with the MD+BL partial regression coefficients.

The lower canines yielded the greatest sexing accuracies of 69.7% on the right side, using a combination of MD and BL (n=132 individuals). On the left side, accuracy was 66.4% (n=132). Combination of the lower canines, lower premolars, and upper 2nd incisors, all with both BL and MD, produced an accuracy of 78.9%, n=57 (Equation 1, Table 2). With

Table 1. Single-tooth regression accuracies (left side only).

Tooth	ULI1	ULI2	ULC	ULP1	ULP2	ULM1	ULM2	ULM3
MD accuracy	58.50%	62.80%	56.80%	56.40%	61.30%	68.10%	58.10%	75%
BL accuracy	66.70%	63.40%	59%	63.90%	63.30%	56%	60.70%	70.30%
MD+BL accuracy	61.70%	61.50%	57%	64.90%	64.70%	62.70%	57.30%	69.40%
Tooth	LLI1	LLI2	LLC	LLP1	LLP2	LLM1	LLM2	LLM3
MD accuracy	59%	55.70%	65.40%	61.20%	63.80%	55.20%	63%	65.50%
BL accuracy	56.70%	55.10%	63.40%	63%	64.80%	59.70%	59%	68.90%
MD+BL accuracy	60.40%	57.70%	66.40%	62.30%	55.20%	63.60%	64.10%	70.20%

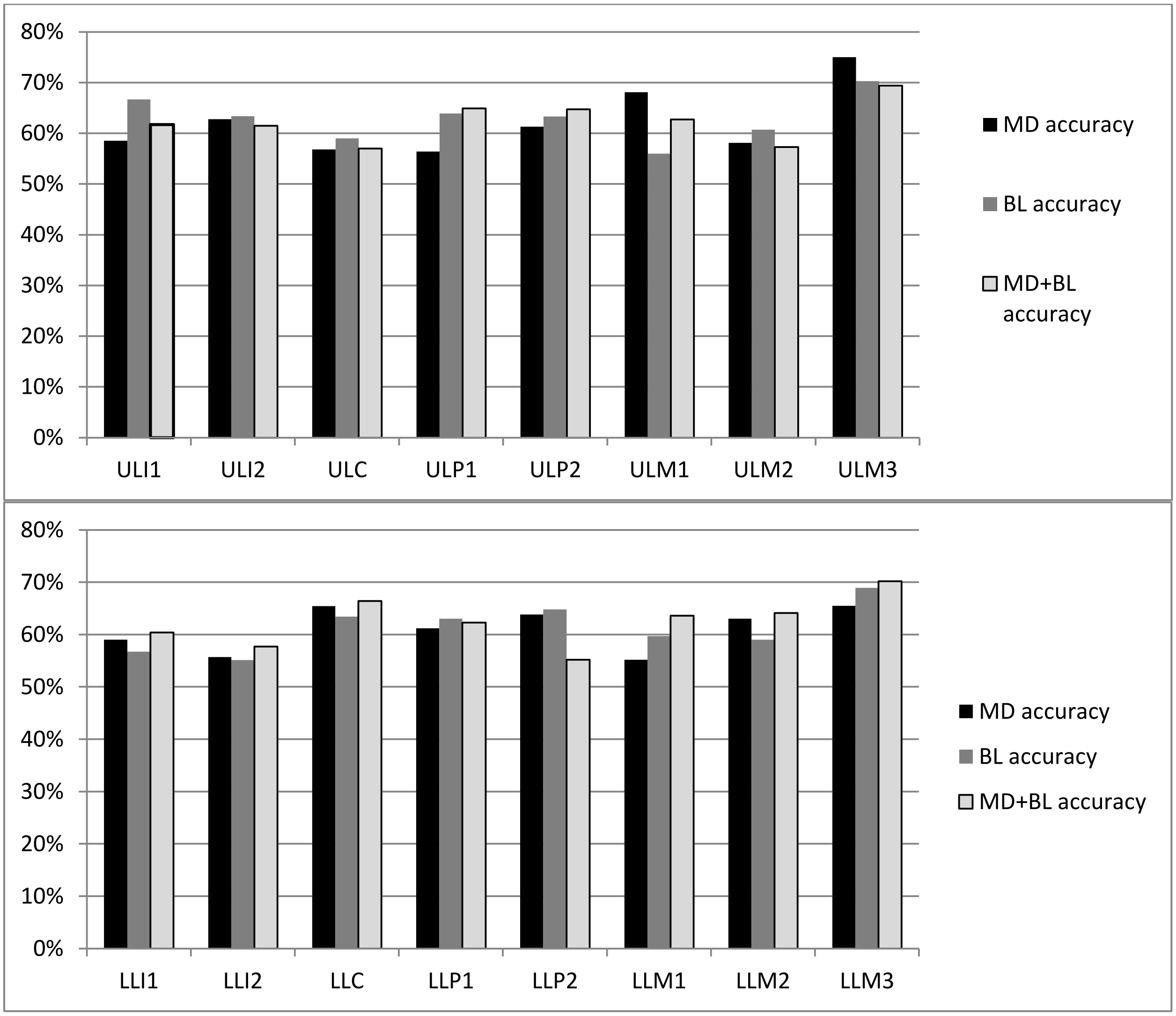

Figure 7. Single-tooth regression accuracies (left side only).

the exception of the lower canines, the teeth that contributed to this 78.9% regression equation yielded more accurate predictions (when regressed initially, by themselves) in the BL dimension than in either MD or combined. However, when only the BL measurements of these three teeth are combined with the lower molar measurements and regressed, the accuracy is only 65.2%. Several other combinations were less accurate than the lower canine alone, and none was more than 78.9% accurate. Adding the next most accurate single tooth (URI1, combined diameters) to the measurements from Equation 1 had the astonishing result of increasing the accuracy to 93.8% when using right side measures (Equation 2, Table 2). This is more accurate than any predictions described by Garn (1964), Adler and Donlon(2010), or Rösing (1983). Left side measures produced a somewhat lower accuracy of 85.4% (Equation 3, Table 2). It is important to consider that with these relatively high-accuracy formulae, the number of individuals to which they can be applied is considerably reduced in comparison to the overall sample because of the large number of teeth needed. The regressions for the left and right sides (2 and 3 on Table 2) could only be applied to 48 of the 202 individuals in the sample. That does not mean the formulae should be discarded, however, since it could be very useful should a sample have at least one unsexed individual with all five teeth present. It should also be noted that a regression equation can still be viable with many partial regression coefficients as long as each coefficient in the equation was represented by a greater number of measurements than the number of coefficients in the equation (Ott and Longnecker, 2010), as was the case with all regression equations produced in this study.

The teeth chosen for the multi-tooth regressions were those that had high accuracies from the single-tooth series and were well-represented by individuals in the sample (few individuals had those teeth missing). The various combinations of measurements yielded accuracies as high as 93.8%[2]. The most useful of these were deemed to be those with at least 75% accuracy (see Table 2), as lower accuracies would not be worth implementing in the field. The variables that contributed to the formulae in this upper range of sexing accuracies were the upper 1st & 2nd incisors, upper 1st & 2nd premolars, and lower canines. These teeth were each present in over half of the individuals of the sample (though fewer individuals had them all). The 93.8% accurate logit equation combined the upper 1st and 2nd incisors, lower canines, and lower 1st and 2nd premolars (combined right side MD and BL diameters for all teeth) and this applied to 26 females and 22 males. An equation with fewer variables that accommodates more individuals was the combination of upper 2nd incisors, lower canines, and both lower molars, reaching an accuracy of 78.9% (combined right side MD and BL diameters for all teeth), which applied to 28 females and 29 males (57 total).

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[2] It was possible to achieve 100% accuracy when all of the teeth that had yielded 61% accuracy or greater on the primary regression series we co-regressed. Variables in this formula were removed systematically to increase the number of applicable individuals. Removing 1 tooth (URP1) retains the 100% accuracy but increases the individual pool to 45. Nonetheless, having so many teeth present (7, with 2 measurements for each), including some that are antimeres of each other, is not a likely scenario for a body that has been left to decay in the field and exposed to taphonomic forces.

Removing variables from regressions based on p-values failed to raise accuracies above the 93.8% accuracy of the above combination. Upon repeating this process on the resulting formula the accuracy dropped down to 86.3%, but it also increased the number of incorporated individuals to 51. This third equation involved the five teeth from the 93.8% equation above, but using only one diameter for each tooth (see Table 2 for specifics), achieved 86.3% accuracy when applied to 26 females and 25 males (51 total). A formula that can reliably sex with 90% accuracy or greater is the superior choice, but there may be occasions when certain individuals lack the requisite teeth for the more accurate formulae. Although most of the regressions included only right side measures (because of the greater on average tooth presence) some of the equations were developed for both sides or included teeth from both sides.

The pooled-sex accuracy of the regression equations presented in Table 2. are not as useful to researchers as the lowest of the single sex accuracies. If the minimum sex-specific accuracy is too low, that shows that the equation is over-classifying one sex. It is therefore important for both accuracies to be high and close together in value. Equations 1 through 5, 7, 8, 10 and 11 have accuracies that are relatively consistent between males and females. The difference in each of these cases is less than 10% and no percentage is below the 75% threshold. Equations 6, 9, 12 and 13, all violate both of these conditions (a greater than 10% difference and one sex has an accuracy below 75%). This is especially egregious with equations 9 and 10, the only single-tooth equations of this Table. The upper third molars had the highest accuracies of any single-tooth regression equations (see Tables 1 and 2) but with such low accuracies for correctly predicting females (33.3% and 38.5%, respectively), these equations are effectively useless.

ROC analysis

ROC analysis was conducted on the most accurate measurements or combination of measurements for the single-tooth regressions (left side only). The same is true for the multi-tooth regression equations that bore the greatest accuracy while maintaining a healthy sample size, as they show the most promise for use in the field. ROC analysis allows researchers to compare the respective areas under the curve (AUC) for different points along the x-axis. Using this information, researchers can choose a measurement value (0.5 mm, for example), that will classify a unit as positive when met or exceeded (≥0.5) and negative when not met (<0.5). In this way, one can select values that fail to capture some true positives in order to reduce the probability of false positives. ROC analysis is particularly suited to situations in which the measured value(s) for a particular individual are far from the threshold value identified by a logistic regression or discriminant function. It allows the information that is available on the size of various teeth to be used to clarify the probability of making a false sex determination for a particular individual. Furthermore, ROC analysis can be used to improve logistic regression equations with poor reported allocation accuracy, so long as the measurements for a particular individual are far removed from the threshold value identified by the equation. In the case of sexing, a researcher can identify specific measurement values and know what percentage of one sex (e.g. males) are likely to fall above the measurement, as well as what percentage of the other sex (females in this case) are also likely to fall above that same measurement value. Thus, ROC analysis can be used to determine the cost-benefit ratio of estimating sex for an individual with a specific measurement value. In other words, it is possible to determine how close to 100% an estimation formula can approach for a single sex without taking on too many false positives. The most useful points along an ROC curve will correctly classify the largest proportion of one sex while accepting less than 20% misclassification of the other. In practice, if a particular skeleton has a measurement of 0.61 mm for a specific dimension, and the ROC output indicates that only 7.8% of females are likely to have a value greater than 0.60 mm, then the individual has only about an 8% chance of being female.

For logistic regression equations with multiple variables, ROC curves can be computed for the logits that result from selected equations. The curve, when males are being selected for, is the plot of sensitivity (the ratio of correctly classified males to the total number of males in the sample) and 1-specificity (the ratio of females incorrectly classified as males to the total number of females in the sample). Table 3 includes the results of the ROC analysis for the most promising equations from Table 2: equations 1, 2 and 3. Measurements (or logits, in this case) that are better suited to distinguishing males from females, will have greater AUC. AUC thus serves as a proxy for the utility of each equation. Equations 2 and 3 are therefore more accurate than equation 1. The range of logits for equation 1 reveals that 82.8% of males will have an equation 1 logit that is $\geq$-0.217, while 25% of females will be incorrectly classified as males at this value. In this same range for equation 1, it shows that 75.9% of males will have a logit score of 0.347 or greater, while only 7.1% of females will have a logit value that is this large or greater. The ratios of sensitivity to 1-specificity are improved in equations 2 and 3 by selecting these alternative threshold values when the circumstances warrant (Tables 2 and 3).

The results of ROC analysis for the single-tooth regressions are presented in Appendix B. The range of logits is restricted to sensitivities above 60% and 1-specificities below 70%. The regression accuracies for this series were considerably lower than those of equations 1 through 3, and this is true for the ROC results as well. AUC for these equation logits ranged from 0.519 (for LLI2) to 0.757 (for ULP1). None of the single-tooth regression equations met the demands of having a 75% or greater sensitivity with a 1-specificity of 20% or less. ULP1 and LLC had the strongest results, where in the former, 62.3% of males have logits of 0.384 or greater, while only 19.5% of females would be misclassified as male at this value or greater. Lower logit scores successfully capture more males, but also misclassify many more females, so that by capturing 86.8% of males (logits $\geq$-0.29), 53.7% of females will be misclassified as male. Appendix C displays the ROC output for individual tooth measurements, rather than regression logits, allowing for simplified sex-estimations using a single variable.

Table 2. Logistic regression equations (combined right side variables).

Equation	Teeth	Logit equation	Female correct%	Male correct%	Total correct%
1	URI2, LRC, LRP1, LPR2	-31.513+(-2.146*URI2MD)+(1.436*URI2BL)+(2.03*LRCMD)+(3.131*LRCBL) +(-.906*LRP1MD)+(-.752*LRP1BL)+(3.313*LRP2MD)+(-1.376*LRP2BL)	82.1% of 28	75.9% of 29	78.9% of 57
2	URI1, URI2, LRC, LRP1, LRP2	-16.074+(-3.798*URI1MD)+(-1.980*URI2MD)+(2.227*URI2BL)+(5.376*LRCMD) +(-2.459*LRP1MD)+(3.854*LRP2MD)	88.5% of 26	84% of 25	86.3% of 51
3	URI1, URI2, LRC, LRP1, LRP2	-71.130+(-10.151*URI1MD)+(5.797*URI1BL)+(-8.831*URI2MD)+(9.485*URI2BL) +(6.927*LRCMD)+(5.644*LRCBL)+(-5.032*LRP1MD)+(-1.489*LRP1BL)+(15.718*LRP2MD) +(-4.792*LRP2BL)	96.2% of 26	90.9% of 22	93.8% of 48
4	ULI1, ULI2, LLC, LLP1, LLP2	-38.128+(.322*ULI1MD)+(-5.33*ULI1BL)+(-1.507*ULI2MD)+(.136*ULI2BL)+(5.701*LLCMD) +(.261*LLCBL)+(-7.067*LLP1MD)+(3.041*LLP1BL)+(6.938*LLP2MD)+(2.281*LLP2BL)	80% of 20	89.3% of 28	85.4% of 48
5	URI1, URI2, LRC, LRP1, LRP2	-23.185+(-4.554*URI1MD)+(2.035*URI1BL+(-1.962*URI2MD)+(1.431*URI2BL)+(5.233*LRCMD) +(1.293*LRCBL)+(-3.98*LRP1MD)+(4.726*LRP2MD)	84.6% of 26	80% of 25	82.4% of 51
6	URI1, URI2, LRC, LRP1, LRP2	-7.694+(-2.316*URI1MD)+(-.556*URI2MD)+(3.366*LRCMD)+(-1.024*LRP1MD)+(2.089*LRP2MD)	85.2% of 27	73.1% of 26	79.2% of 53
7	URI1, LRC, LRP2	-10.255+(-2.621*URI1MD) +(3.056*LRCMD)+(1.544*LRP2MD)	84.4% of 32	78.6% of 27	81.7% of 59
8	URI1, URI2, URP1, LRC	-29.720+(-1.771*URI1MD)+(-.221*URI1BL)+(-1.564*URI2MD)+(1.198*URI2BL) +(3.262*URP1MD)+(.632*URP1BL)+(2.428*LRCMD)+(.317*LRCBL)	79.2% of 24	76.2% of 21	77.8% of 45
9	URI1, URP1, LRC	-30.492+(-1.681*URI1MD)+(-.288*URI1BL)+(2.345*URP1MD)+(.531*URP1BL) +(1.969*LRCMD)+(1.431*LRCBL)	86.2% of 29	68.2% of 22	78.4% of 51
10	ULP1, LLC, LLP1, LLP2, URI2, URP1, LRC, LRP1	-1423.813+(18.137*ULP1MD)+(-85.877*ULP1BL)+(-103.015*LLCMD)+(98.952*LLCBL) +(-155.3*LLP1MD)+(38.054*LLP1BL)+(26.468*LLP2MD)+(-2.439*LLP2BL)+(-66.098*URI2MD) +(44.284*URI2BL)+(37.416*URP1MD)+(56.859*URP1BL)+(-41.584*LRCMD)+(-63.18*LRCBL) +(161.819*LRP1MD)+(35.021*LRP1BL)	100% of 18	100% of 19	100% of 37
11	ULP1, LLC, LLP1, LLP2, URI2, LRC, LRP1	-15338.598+(-179.066*ULP1MD)+(1113.023*ULP1BL)+(1661.192*LLCMD)+(-554.775*LLCBL) +(-630.015*LLP1MD)+(-158.651*LLP1BL)+(608.588*LLP2MD)+(-905.839*LLP2BL) +(-583.471*URI2MD)+(-593.193*URI2BL)+(613.688*LRCMD)+(1159.582*LRCBL) +(329.677*LRP1MD)+(69.028*LRP1BL)	100% of 21	100% of 24	100% of 45
12	URM3	-6.7222+(.844*URM3MD)	33.3% of 12	100% of 32	81.8% of 40
13	ULM3	-7.041+(.849*ULM3MD)	38.5% of 12	95.7% of 23	75% of 35

Table 3. ROC results for male and female regression logits.

Equation#	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
1	.89	-.217	.828	.250	-.266	.714	.138
		-.165	.793	.250	-.239	.714	.172
		-.114	.793	.214	-.217	.750	.172
		-.088	.793	.179	-.165	.750	.207
		.054	.759	.179	-.114	.786	.207
		.214	.759	.143	-.088	.821	.207
		.275	.759	.107			
		.347	.759	.071			
2	.92	-.038	.840	.115	-.336	.769	.160
		.194	.800	.115	-.294	.808	.160
		.284	.800	.077	-.239	.846	.160
		.400	.760	.077	-.038	.885	.160
		.571	.720	.077	.194	.885	.200
		.650	.720	.038	.284	.923	.200
					.400	.923	.240
3	.97	-.756	.955	.192	-.756	.808	.045
		-.634	.909	.192	-.634	.808	.091
		-.478	.909	.154	-.478	.846	.091
		-.356	.909	.115	-.356	.885	.091
		-.238	.909	.077	-.238	.923	.091
		.271	.909	.038	.271	.962	.091
		.812	.864	.038	.812	.962	.136
		1.44	.864	.000	1.44	1.000	.136

Asymmetry

T-tests of the directional asymmetry (DA) scores on indexed tooth crown measurements showed no statistically significant directional asymmetry ($\alpha/2=0.025$). T-tests on the AA scores revealed that every indexed tooth, except for upper 1st molars, displayed fluctuating asymmetry that was statistically significant (see Table 4). Since it may be possible that males and females of the sample had significantly different levels of fluctuating asymmetry, the scores were subjected to binary logistic regression to determine their utility in sex-estimation. None of the DA scores were strong enough to be useful for sexing purposes. Accuracies from this series of regressions were all below 60%.

AMTL sex comparison

The rates of antemortem tooth loss (AMTL) were calculated for both sexes. In every case, females had lower percentages of AMTL per tooth. The results had a range of 6.6% (female lower canines, both left and right) to 55.6% AMTL (male upper left 3rd molars) and in all but 4 instances (URM3, LLM3, LRP2, LRM1) males had greater rates of AMTL than females. The differences were tested for statistical significance by way of a 1 sample T-test (see Table 5). AMTL differences were significant in upper left 2nd premolars, upper left 1st & 3rd molars, upper right 1st molars, lower left 1st molars, lower right 2nd premolars, and lower right 1st & 3rd molars ($\alpha=0.5$).

AMTL age comparison

The figure below illustrates how in this sample AMTL rates increase with age. The number of individuals in each age category is displayed as well. Ages 70 years and above are designated with asterisks because they represent individuals who were selected for the sample either because they had teeth present, or because sufficient time remained for the inclusion of edentulous individuals of those ages. Some cases of fluctuation notwithstanding, overall, the average number of missing teeth per age category was positively correlated with age at death. Those under 40 years of age at death exhibited very few missing teeth due to AMTL and individuals over 90 years were completely edentulous. Rates were relatively stable between 40 and 59 years (with a mean of 9.5 missing teeth and a standard deviation of 0.93). They rose and proceeded to stabilize again from 60 to 84 years (15.58 mean, 2.37 standard deviation). Disregarding the ages of 70 years and older, there is still a noticeable rise in AMTL rates between 45 and 69 years.

Table 4. Absolute asymmetry one-sample T-test results, significant results highlighted.

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
UI1DA	9.566	65	.000	.0249084	.019708	.030109
UI2DA	8.890	71	.000	.0410967	.031879	.050314
UCDA	7.125	81	.000	.0334117	.024081	.042742
UP1DA	5.967	68	.000	.0341689	.022743	.045595
UP2DA	5.961	62	.000	.0495420	.032928	.066156
UM1DA	1.785	48	.081	.0720926	-.009103	.153288
UM2DA	2.516	64	.014	.0767444	.015812	.137677
UM3DA	5.049	19	.000	.0534613	.031299	.075624
LI1DA	10.137	84	.000	.0386728	.031087	.046259
LI2DA	7.849	84	.000	.0418518	.031248	.052456
LCDA	11.467	112	.000	.0300919	.024892	.035292
LP1DA	10.978	98	.000	.0485550	.039777	.057333
LP2DA	2.682	77	.009	.0685412	.017656	.119426
LM1DA	6.974	37	.000	.0308599	.021894	.039826
LM2DA	8.592	52	.000	.0359811	.027578	.044384
LM3DA	5.828	31	.000	.0491371	.031941	.066334

Table 5. AMTL one-sample T-test results, significant results highlighted.

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
ULI1	9.041	1	.070	.2215000	-.089802	.532802
ULI2	3.694	1	.168	.1810000	-.441604	.803604
ULC	3.022	1	.203	.1375000	-.440632	.715632
ULP1	8.153	1	.078	.2405000	-.134333	.615333
ULP2	13.057	1	.049	.2285000	.006141	.450859
ULM1	98.714	1	.006	.3455000	.301028	.389972
ULM2	4.118	1	.152	.3130000	-.652672	1.278672
ULM3	36.067	1	.018	.5410000	.350407	.731593
URI1	4.292	1	.146	.206000	-.40390	.81590
URI2	5.938	1	.106	.190000	-.21660	.59660
URC	5.140	1	.122	.1465000	-.215627	.508627
URP1	10.814	1	.059	.2325000	-.040683	.505683
URP2	6.744	1	.094	.2630000	-.232542	.758542
URM1	356.000	1	.002	.3560000	.343294	.368706
URM2	5.110	1	.123	.2785000	-.413988	.970988
URM3	17.138	1	.037	.4970000	.128520	.865480
LLI1	4.292	1	.146	.206000	-.40390	.81590
LLI2	4.568	1	.137	.1690000	-.301130	.639130
LLC	5.552	1	.113	.0805000	-.103740	.264740
LLP1	4.568	1	.137	.0845000	-.150565	.319565
LLP2	10.684	1	.059	.203000	-.03842	.44442
LLM1	28.161	1	.023	.4365000	.239554	.633446
LLM2	7.077	1	.089	.368000	-.29272	1.02872
LLM3	29.560	1	.022	.3695000	.210672	.528328
LRI1	6.797	1	.093	.2005000	-.174333	.575333
LRI2	3.258	1	.190	.1515000	-.439339	.742339
LRC	7.286	1	.087	.0765000	-.056915	.209915
LRP1	10.778	1	.059	.1455000	-.026034	.317034
LRP2	13.552	1	.047	.1965000	.012260	.380740
LRM1	20.067	1	.032	.4515000	.165610	.737390
LRM2	6.026	1	.105	.3465000	-.384107	1.077107
LRM3	46.600	1	.014	.3495000	.254203	.444797

CHAPTER 5

Discussion

Regressions

The best results from the regression equations produced for this study were those that incorporated two measurements from at least four teeth. The allocation accuracy of the equations, with percentages of correctly classified individuals in the mid to high 80s and low 90s, falls in line with previous tests of odontometric sexing techniques. The most accurate sex-estimation equations from prior studies have fallen into an 87%-97% range of correct classification (Ditch & Rose, 1972; Garn et al., 1967, 1977, 1979; Rösing, 1983). Of these previous studies, Rösing's (1983) yielded the most accurate sex-estimation equation, requiring four teeth (upper and lower canines and lateral incisors) and 16 measurements (MD and BL diameters as well as crown and root heights) and it had an accuracy of 97.3% and applied to 37 out of 55 individuals from his sample. He presented four similarly accurate equations and 12 more that fell into a 90-95% range. Ditch and Rose's (1972) study had a range of accuracies from 88.4 to 95.5%, with the most accurate requiring five teeth (upper and lower canines, 1st and 2nd premolars, and 1st molars) with one diameter measurement from each tooth (varied by tooth) and applied to 44 of 87 individuals. These two studies were able to apply their highest-accuracy equations to a larger percentage of their original respective samples than was possible with the present study, but this will vary by population, regardless of methods. The relatively high estimation accuracies from the present and previous studies underscore the usefulness of odontometrics as a means of corroborating the results of traditional morphological techniques or replacing them when individuals lack viable pelves and/or crania.

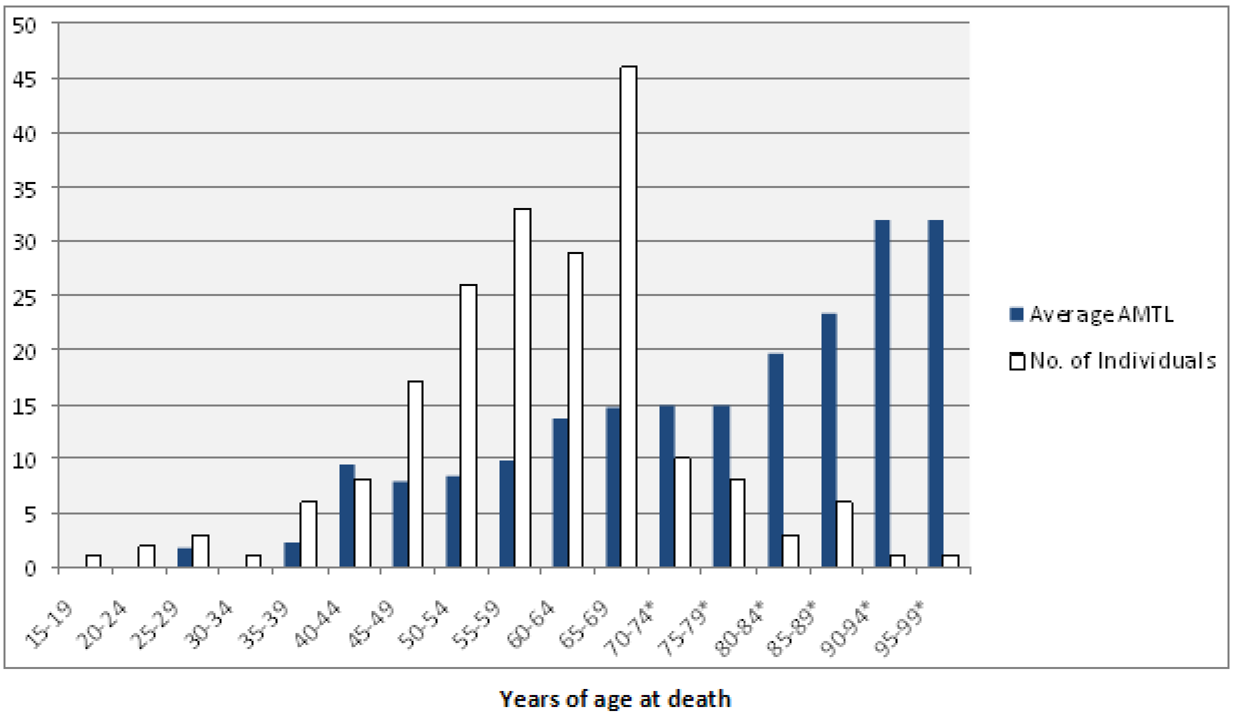

Figure 8. Individuals per age category and average number of missing teeth due to AMTL.

Table 6. AMTL rates by number of missing teeth (*ages over 70).

15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74*	75-79*	80-84*	85-89*	90-94*	95-99*
0	0	1.7	0	2.3	9.5	7.9	8.4	9.9	13.6	14.7	15	14.9	19.7	23.3	32	32
1	2	3	1	6	8	17	26	33	29	46	10	8	3	6	1	1

The results of the binary logistic regressions for sex-estimation suggest that the usefulness of odontometrics depend on how many and which types of teeth are present in the individuals under investigation. Estimations will be much more accurate if an individual of unidentified sex has every tooth present, as the combination of many teeth is required for the most accurate regression formulae. With enough teeth, the individual(s) may be sexed with as much accuracy as with traditional morphological techniques. Increasing the accuracy of regressions by changing the combination of variables usually led to a small subset of the sample that could be sexed. Whether or not the benefits of improved accuracy outweigh the disadvantages of reduced sample size will depend on specific circumstances, such as the precise number of individuals and teeth in a given sample. Most of the regressions yielded accuracies in the 75-85% range, so these should be used in conjunction with the more traditional techniques where possible.

The more teeth that are included as partial regression coefficients, the fewer individuals from a sample there are to whom the regression formula can be applied (assuming some or all individuals are missing different types of teeth). It was possible for some combinations of teeth to sex as accurately as traditional techniques, but only by excluding those individuals who lacked all the necessary teeth, which could make for nonviable estimation equations. For example, for this sample sex-estimation accuracy increases slightly on the left side and is reduced slightly on the right when the two upper premolars replace the upper 1st incisors, but the pool of individuals is also reduced in both cases. The balance between accuracy and viability of the regression formulae is best for those that integrate at least three teeth (see Table 2). The teeth in question were selected in part for being some of the more common teeth associated with individuals in the collection. Since these individuals were buried in sandy pits for defleshing, the degree of postmortem tooth loss should approximate those buried in the ground in similar conditions elsewhere. One could therefore have a reasonable chance to have the necessary teeth to apply an equation on Table 2 should an individual of undetermined sex from Chiang Mai or a similar region be one's subject of study. The researcher should select the equation that best fits with the teeth that are present in the individual. Should all teeth listed for equations 7 and/or 8 be present, each with two measureable diameters, results of the regression become very accurate (nearly 100%). However, it is unlikely that many such cases will arise, since only 45 of 202 measured individuals qualified in this sample. Even less accurate formulae can exclude well over half of the sample size, as none of the equations from Table 2 include more than 59 of 202 sampled individuals. In this population, an odontometric sex-estimation strategy may serve as a useful supplement to morphological methods, but will only apply to a small subsection of individuals in a particular study.

The best results from employing odontometric binary logistic regression formulae would be achievable with a tiered formula system. The most accurate formulae, such as equation 8 (Table 2), could be applied to those in the sample with all seven teeth (14 measurements per person). The next most accurate formula could then be applied to those not included in the first phase, and so on until every formula with over 75% accuracy was applied, if necessary. This way, some information will be gained on a much larger percentage of a sample than from just applying one formula.

Odontometric sex-estimation may be particularly useful for subadults, whose permanent teeth express greater sexual dimorphism than their cranial and postcranial skeletons. With subadults, the question of whether individuals in the sample will have the necessary teeth is highly pertinent, as the age at death range is limited to those whose necessary permanent teeth have erupted, but are not yet sexually dimorphic enough in the pelvic and cranial regions for the application of traditional techniques. That age range is particularly problematic for archaeological contexts because it is a window wherein few deaths tend to occur. Subadults typically represent a large percentage of burials at mortuary sites due to infant mortality rates that were far higher in prehistory than in the developed world today. Once subadults make it past their early childhoods, they will have developed immune systems that are essentially mature and are less susceptible to disease than their infant counterparts. They may, however, still be considered too young for difficult or dangerous labor that results in the deaths of older individuals. Individuals between 10 and 14 years comprised only 3.2% of all of the burials at the Neolithic site of Khok Phanom Di, despite having the most subadult burials of any prehistoric site in Thailand (Tayles, 1999). The vast majority of those subadults from this site were infants, and therefore, not viable subjects for odontometric analysis (48.1% of the individuals were aged 0-4 years at death). With that in mind, the odontometric sexing strategy explored in this paper could hypothetically still apply to slightly more individuals from Khok Phanom Di than traditional techniques (47.4% of the individuals rather than 44.2%). Given that AMTL is less common in younger individuals, those few subadults are more likely to be viable subjects for odontometric analysis than older individuals.

ROC analysis provides the added benefit, when working with regression equations, of allowing a researcher to see how useful a logit is for each sex. The ROC analysis of the regression logits offers an example of how the odontometric data may yield more accurate results, depending on what one is looking for. A researcher may compare logit results from their own sample with the ROC curve for equations 1 through 3, as shown on Table 3, to estimate the chances of the individual being one sex over another. Although some logits will result in a smaller than desired number of individuals being classified correctly, the ROC data may show that the benefit is a reduced number of misclassfied individuals. This would demand certain individuals to be unclassified, and therefore of indeterminate sex. In a different situation, a researcher may be willing to accept a higher than normal amount of misclassified individuals if capturing as many true positives as possible was desired. These situations could arise in forensic investigations, such as the repatriation of soldiers, where many bodies are exhumed and males are of primary interest. Use of ROC in this way could also benefit archaeologists who are interested in analyzing aspects of a particular sex/gender.

Because the equations represented on Table 3 were relatively accurate, the benefits of ROC analysis are reduced. The regression logits had sufficient classifying power that ROC investigation would not be necessary in many situations. ROC analysis on lower-accuracy equations, such as the single-tooth regression results from Table 1, gives researchers the opportunity to closely examine the estimation capabilities of those equations at different logit score levels. ROC curves for single-tooth equations also provide the benefit to researchers interested in sexing individuals who lack the required teeth for the most accurate multi-tooth regression formulae. Should a researcher have a single tooth, they can take one or two measurements and find the corresponding logit score on the chart of ROC results (Appendix B), and if the ratio of sensitivity to 1-specifictiy is in line with the project goals, that tooth may be useful when the accuracy from the regression equation alone may not have been high enough for confidence in the outcome. ROC is therefore beneficial when one can compare a logit resulting from regression equation 1 (Table 2.) with the ROC output from Table 3. A value of 0.347 or greater is shown to capture 75.9% of males while only misclassiying 7.1% of females. However, 24.1% of males would necessarily fall into the indeterminate category using a threshold value of 0.347.

Sexual dimorphism significance

İşcan et al. (1998) established metric sexual dimorphism standards for Chinese, Japanese, and Thai populations based on the humerus. Thai measurements were the smallest of all groups but the most sexually dimorphic. The opposite was true of the Chinese, with the Japanese being intermediate in both fields. The study showed that Thai humeri are sufficiently sexually dimorphic for 97.1% of a sample to be accurately sexed, while only 85.4% and 95.5% of Chinese and Japanese individuals were accurately sexed, respectively. King et al. (1998) found similar patterns amongst Thai femurs when compared with Chinese, South African, and American populations. Thai femur measurements were able to accurately sex 94.2% of individuals, while the other groups (with their own respective formulae) had accuracies in 85.7-93.4% range. All Thai femur measurements from their sample were smaller than those of the comparison groups, reinforcing İşcan et al.'s (1998) conclusions that Thais tend to have smaller bodies with greater sexual dimorphism than other groups. When formulae derived from the comparison groups were applied to the Thai femurs, allocation accuracy fell to 87.1% (Chinese), 27.1% (South Africans), 44.3% (European-Americans) and 65.7% (African-Americans), suggesting that Thai sexual dimorphism patterns are most similar with those of the Chinese, but that they are still distinctly different. These accuracy differences highlighted the importance of population specificity in sex-estimation formulae. The Thai long bones from both of these studies were conducted with individuals from the Chiang Mai area who had died in the 1990s, so they should resemble the individuals from the present study.

The degree to which teeth exhibit sexual size dimorphism also varies from region to region (Garn et al., 1967). In general, odontometric sexual dimorphism is relatively low in humans, around 2-6% (Scott and Turner, 1997), and the people of present day Southeast Asia are known for having particularly low levels (Garn, 1967; Indriati, 2007). Body size and odontometric sexual dimorphism are not necessarily controlled by the same genetic factors, so it may be enlightening to compare these patterns for the same group of individuals. The odontometric sexual dimorphism of the Chiang Mai collection falls in line with the lower range of Garn et al.'s (1967) rankings of worldwide human tooth sexual size dimorphism. According to Garn et al. (1967), low levels of sexual dimorphism are more prevalent when there is more genetic diversity within a population. Chiang Mai is one of the largest cities in Thailand, and is a major draw for tourists and expatriates. It is unlikely that the relatively high rates of sexual dimorphism reported by İşcan et al. (1998) and King et al. (1998) are the result of genetic isolation. Instead, the combination of small body size and high sexual dimorphism may relate to genetic predisposition and a low stress environment, respectively. Other research indicates that sexual dimorphism may peak when protein consumption is at either a high or low extreme (France, 1983), so the small body size and high sexual dimorphism may relate to protein deficiency. Southeast Asia hosted a series of military conflicts during the 20th century, any of which could have resulted in the kind of nutritional stress that might account for the patterns visible in modern Chiang Mai.

Canines are widely regarded as the most sexually dimorphic teeth in humans and many other species (Garn et al., 1965, 1967; Hillson, 1996; Scott and Turner, 1997). Indeed, this was confirmed for the Chiang Mai sample as well, but only for mandibular canines. Maxillary canines were not useful indicators of sex, whether as solitary or partial regression coefficients. Garn et al. (1967) recorded the upper canines as among the more dimorphic teeth, but this was not the case for the Chiang Mai sample. They also remarked that the patterns of sexual dimorphism for the different tooth types varies between populations as does the magnitude, so this may explain why the upper canine proved ineffectual for the present study's sex-estimation purposes.

Teeth develop to their final, adult size as soon as the crowns have formed within the crypts. While they are developing, specifically during the period of amelogenesis, external factors may impact how large the teeth will become. Permanent teeth serve as a record of childhood nutritional intake and disease load, albeit to a lesser degree than long bones. Garn et al. (1965) described how teeth are 1/3 as responsive to episodes of stress as long bones, but they do respond. Physiological stress may result in smaller overall tooth sizes, greater asymmetry between dental antimeres, or both. The sexual dimorphism visible in the Chiang Mai sample has been influenced, to some degree, by environmental factors, such as malnutrition or infectious disease. Further research is necessary in order to assess to what extent this is the case.

Asymmetry significance

Fluctuating asymmetry (FA), being an expression of developmental plasticity, results from the same sort environmental factors that can affect sexual dimorphism in tooth size. Odontometric FA in the Chiang Mai collection proved to be widespread. FA was statistically significant in every tooth except UM1, implying that UM1 may be more resistant to asymmetrogenic factors than other teeth. The 1st upper molar crown develops over the first two to three years after birth, while other crowns are not fully developed until after the 4th or 5th year (Ferembach et al., 1980). The period of development for UM1 overlaps with the period of nursing to a much greater extent than would be the case for other permanent teeth. The buffering of environmental factors afforded to infants by breast milk may account for the stability of UM1 in this sample. Kieser and Groenenveld's (1988) study on South Africans showed that while UM1 exhibited less FA than most teeth, upper and lower canines were the two most symmetric tooth types. This pattern held true for both European and indigenous South Africans, but not for the study's comparison group—the Lengua of Paraguay. Indeed the Lengua, like the Chiang Mai sample, had the least amount of asymmetry in UM1, though canines were still among the more symmetrical teeth. These statistics support the notion that the patterns of FA are variable by population. Unfortunately, because quality of life was so different between European and indigenous South Africans in the 1980s, it is unclear to what extent environment or genetics are more culpable for the differences in patterns. It is also unknown whether the forces that affected most of the teeth for the Chiang Mai sample were abnormally high, but the presence of FA does suggest that developmental stress was a common occurrence for the Thai children of the area. As with sexual dimorphism, further research is necessary to assess how much and what kinds of stress is necessary for FA to be expressed at the levels evident in the Chiang Mai sample.

AMTL significance

Analyzing the meaning to the amount of antemortem tooth loss (AMTL) in the Chiang Mai sample is difficult, if only due to the high ages of most of the individuals. It is understandable that 3rd molars would have the highest AMTL rates at 55.6% since they are often surgically ablated. The rate may have been even higher had the sample been comprised of wealthier individuals with more access to dental surgery, however the economic status of the individuals in question in unknown. It is of interest to researchers that with only four exceptions, males had greater AMTL rates than females. This result is opposite of the general worldwide trend of females having higher caries rates than males. This may stem from biological differences, such as a disparity in resistance to caries and/or periodontal infection or the amount/acidity of saliva. It may also be due to behavioral differences such as oral care, diet, or cariogenic food consumption and/or processing.

Unlike FA, AMTL tends to reflect maladies sustained later in an individual's life, and is much more common in adults than subadults. For this reason, subadults with significant AMTL may yield the most useful information about oral health in a population, as they should be less common than adults with AMTL. The only subadult from this sample, a 15 year-old, was not missing any teeth due to AMTL, however; only after about 40 years of age at death were there more than one or two missing teeth per average individual. Drawing conclusions from AMTL rates from this sample's youngest or oldest individuals may be also be problematic due to the lack of individuals representing those age groups in the sample. Very few individuals in this collection were under the age of 40 years at death (n=10) or older than 80 years at death (n=11).

CHAPTER 6

Conclusion

According to İşcan et al. (1998) and King et al. (1998), Thais born in the 20^{th} century appear to be small but sexually dimorphic in body size. Other studies (Garn et al., 1967, Indriati, 2007) have also shown that tooth size sexual dimorphism in Southeast Asia is much less than that of body size. Despite the results of these latter studies, teeth in a modern Thai sample are sufficiently sexually dimorphic for sexing purposes, but only when multiple teeth are combined, whereas a single long bone such as a humerus or femur may yield results of equal or greater accuracy. When odontometric variables are combined, however, they can yield surprisingly accurate sex-estimations.

For the 202 individuals sampled from the Chiang Mai anatomical collection, patterns of dental sexual dimorphism, fluctuating asymmetry, and antemortem tooth loss have been established in the present study. These patterns may be useful for analyzing individuals from modern day Thailand and have the potential to be applied to prehistoric Thais as well. The mix of ancestral backgrounds represented in present-day individuals living in and around Chiang Mai is not consistent throughout time, nor are the environmental factors that can impact tooth size. However, the odontometric patterns from the Chiang Mai sample will likely have greater parity with Southeast Asians of other time periods than with individuals from other regions of the world. The extent to which this is true is a potential subject for future research.

As has been demonstrated by this study, tooth size is a viable means to estimate sex given a reference sample of similar genetic and environmental background. This is particularly true when multiple teeth are used to estimate sex rather than a single tooth, which would yield poor results on its own. Mandibular canines and premolars and maxillary incisors proved to be the teeth that contributed to the most accurate sex-estimation formulae, particularly when combined as partial regression coefficents. There is no formula that is clearly the best for use in any situation, however, since accuracy and applicability of odontometric sex-estimation equations depend on the number of available teeth and their preservation quality. An individual with all or most teeth remaining in place will be more likely to be sexed correctly than an individual missing most of their teeth. 100% of individuals in this sample with upper right lateral incisors, both upper 1st premolars, both lower canines, both lower 1st premolars, and lower left 2nd premolars were sexed correctly, provided that both mesiodistal and buccolingual measurements could be taken. When fewer teeth were available, accuracy was reduced. 78.9% of individuals with upper lateral incisors, lower canines, and both lower premolars (from one side) were sexed correctly. Individuals with severe wear, caries, or postmortem damage or loss of teeth can prevent one or both measurements from being taken. Therefore, the best formula to use in a particular situation will be the one that includes measurements from as many teeth as are available, provided that they are of the incisor, canine, and premolar types that tend to give the best results.

With techniques such as ROC in conjunction with binary logistic regression, unknown individuals can be sexed with a better understanding of how many true and false positives (correct and incorrect classifications of a certain sex, respectively) are likely to result from a particular regression logit value. The accuracy afforded to the single-tooth regressions after ROC analysis still does not achieve the high percentages required for forensic purposes, but for archaeological research, there may be individuals whose logits are sufficiently distant from zero to definitively classify them as male or female. ROC allows researchers to detect at what point those logits from an individual's tooth measurements are past the threshold where a correct classification is highly likely and an incorrect classification is highly unlikely.

The individuals for which odontometric sex-estimation are the most appropriate are those who cannot be sexed traditionally (through morphological or craniometric techniques) or if those techniques bear indeterminate results. Such individuals may have suffered craniofacial trauma or remains may have experienced postmortem damage. The individual's teeth would need to be present and in a measureable state, however. The more teeth that are present, the better results are possible, especially if those teeth include upper incisors, lower canines, 1st upper premolars and 2nd lower premolars, since those teeth were most frequently associated with accurate sexing formulae.

The Chiang Mai sample exhibited significant fluctuating asymmetry (FA) in nearly every tooth at an alpha level of 0.05. While FA is a general indicator of stress, the amount of stress needed to produce the FA levels seen in this study has yet to be determined for this sample. The unique combination of genetic and environmental factors that can influence tooth size in a region demand specific data on growth and development in Thailand before the results presented in this study can be fully interpreted.

There is room for future research with the teeth of the Chiang Mai collection and elsewhere in Southeast Asia. Stepwise discriminant function analysis should be conducted on the same data as the present study to compare the efficacy with binary logistic regression. In addition, other regions in Southeast Asia should have odontometric patterns established to assess the relationship between areas, especially if tooth and long bone measurements can be collected from the same individuals.

Odontometrics might have a future in geometric morphometrics and other 3D digitizing and analysis applications. Highly accurate geometrical models of teeth may ameliorate much of the time-consumption and observer error that prevents odontometric analysis from gaining popularity. The greater precision may even prove to yield more accurate analytical results than what is possible with traditional by-hand measurements. Comparisons between the interpersonal variability of tooth size and that of body size may yet lead to revelations about stress events and regional differences in canalization for those respective developmental arenas. Databases of digitized dentition have the potential to be used for high-precision analyses of variation between groups and time periods, for studies of human health, development, and sexual dimorphism.

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APPENDICES

Appendix A

Summary of measurements

		Cases					
		Valid		Missing		Total	
	Sex	N	Percent	N	Percent	N	Percent
ULI1 md	F	35	.5	41	.5	76	1.0
	M	47	.4	79	.6	126	1.0
ULI1 bl	F	39	.5	37	.5	76	1.0
	M	57	.5	69	.5	126	1.0
ULI2 md	F	35	.5	41	.5	76	1.0
	M	59	.5	67	.5	126	1.0
ULI2 bl	F	39	.5	37	.5	76	1.0
	M	62	.5	64	.5	126	1.0
ULC md	F	48	.6	28	.4	76	1.0
	M	63	.5	63	.5	126	1.0
ULC bl	F	50	.7	26	.3	76	1.0
	M	67	.5	59	.5	126	1.0
ULP1 md	F	43	.6	33	.4	76	1.0
	M	58	.5	68	.5	126	1.0
ULP1 bl	F	43	.6	33	.4	76	1.0
	M	54	.4	72	.6	126	1.0
ULP2 md	F	36	.5	40	.5	76	1.0
	M	57	.5	69	.5	126	1.0
ULP2 bl	F	37	.5	39	.5	76	1.0
	M	53	.4	73	.6	126	1.0
ULM1 md	F	29	.4	47	.6	76	1.0
	M	43	.3	83	.7	126	1.0
ULM1 bl	F	33	.4	43	.6	76	1.0
	M	42	.3	84	.7	126	1.0
ULM2 md	F	37	.5	39	.5	76	1.0
	M	49	.4	77	.6	126	1.0
ULM2 bl	F	38	.5	38	.5	76	1.0
	M	46	.4	80	.6	126	1.0
ULM3 md	F	13	.2	63	.8	76	1.0
	M	23	.2	103	.8	126	1.0
ULM3 bl	F	13	.2	63	.8	76	1.0
	M	24	.2	102	.8	126	1.0

Appendix A (continued)

		Cases					
		Valid		Missing		Total	
	Sex	N	Percent	N	Percent	N	Percent
URI1 md	F	43	.6	33	.4	76	1.0
	M	45	.4	81	.6	126	1.0
URI1 bl	F	42	.6	34	.4	76	1.0
	M	57	.5	69	.5	126	1.0
URI2 md	F	41	.5	35	.5	76	1.0
	M	54	.4	72	.6	126	1.0
URI2 bl	F	43	.6	33	.4	76	1.0
	M	66	.5	60	.5	126	1.0
URC md	F	48	.6	28	.4	76	1.0
	M	59	.5	67	.5	126	1.0
URC bl	F	49	.6	27	.4	76	1.0
	M	62	.5	64	.5	126	1.0
URP1 md	F	42	.6	34	.4	76	1.0
	M	54	.4	72	.6	126	1.0
URP1 bl	F	41	.5	35	.5	76	1.0
	M	54	.4	72	.6	126	1.0
URP2 md	F	37	.5	39	.5	76	1.0
	M	56	.4	70	.6	126	1.0
URP2 bl	F	39	.5	37	.5	76	1.0
	M	52	.4	74	.6	126	1.0
URM1 md	F	35	.5	41	.5	76	1.0
	M	52	.4	74	.6	126	1.0
URM1 bl	F	35	.5	41	.5	76	1.0
	M	54	.4	72	.6	126	1.0
URM2 md	F	42	.6	34	.4	76	1.0
	M	57	.5	69	.5	126	1.0
URM2 bl	F	45	.6	31	.4	76	1.0
	M	58	.5	68	.5	126	1.0
URM3 md	F	12	.2	64	.8	76	1.0
	M	32	.3	94	.7	126	1.0
URM3 bl	F	13	.2	63	.8	76	1.0
	M	33	.3	93	.7	126	1.0

Appendix A (continued)

	Sex	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
LLI1 md	F	41	.5	35	.5	76	1.0
	M	59	.5	67	.5	126	1.0
LLI1 bl	F	45	.6	31	.4	76	1.0
	M	59	.5	67	.5	126	1.0
LLI2 md	F	48	.6	28	.4	76	1.0
	M	58	.5	68	.5	126	1.0
LLI2 bl	F	48	.6	28	.4	76	1.0
	M	59	.5	67	.5	126	1.0
LLC md	F	56	.7	20	.3	76	1.0
	M	80	.6	46	.4	126	1.0
LLC bl	F	57	.8	19	.3	76	1.0
	M	85	.7	41	.3	126	1.0
LLP1 md	F	53	.7	23	.3	76	1.0
	M	81	.6	45	.4	126	1.0
LLP1 bl	F	52	.7	24	.3	76	1.0
	M	83	.7	43	.3	126	1.0
LLP2 md	F	48	.6	28	.4	76	1.0
	M	65	.5	61	.5	126	1.0
LLP2 bl	F	47	.6	29	.4	76	1.0
	M	69	.5	57	.5	126	1.0
LLM1 md	F	25	.3	51	.7	76	1.0
	M	33	.3	93	.7	126	1.0
LLM1 bl	F	28	.4	48	.6	76	1.0
	M	39	.3	87	.7	126	1.0
LLM2 md	F	35	.5	41	.5	76	1.0
	M	46	.4	80	.6	126	1.0
LLM2 bl	F	34	.4	42	.6	76	1.0
	M	49	.4	77	.6	126	1.0
LLM3 md	F	20	.3	56	.7	76	1.0
	M	38	.3	88	.7	126	1.0
LLM3 bl	F	20	.3	56	.7	76	1.0
	M	41	.3	85	.7	126	1.0

Appendix A (continued)

	Sex	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
LRI1 md	F	38	.5	38	.5	76	1.0
	M	60	.5	66	.5	126	1.0
LRI1 bl	F	43	.6	33	.4	76	1.0
	M	63	.5	63	.5	126	1.0
LRI2 md	F	46	.6	30	.4	76	1.0
	M	60	.5	66	.5	126	1.0
LRI2 bl	F	47	.6	29	.4	76	1.0
	M	74	.6	52	.4	126	1.0
LRC md	F	58	.8	18	.2	76	1.0
	M	80	.6	46	.4	126	1.0
LRC bl	F	56	.7	20	.3	76	1.0
	M	88	.7	38	.3	126	1.0
LRP1 md	F	47	.6	29	.4	76	1.0
	M	76	.6	50	.4	126	1.0
LRP1 bl	F	48	.6	28	.4	76	1.0
	M	75	.6	51	.4	126	1.0
LRP2 md	F	44	.6	32	.4	76	1.0
	M	65	.5	61	.5	126	1.0
LRP2 bl	F	44	.6	32	.4	76	1.0
	M	69	.5	57	.5	126	1.0
LRM1 md	F	26	.3	50	.7	76	1.0
	M	28	.2	98	.8	126	1.0
LRM1 bl	F	26	.3	50	.7	76	1.0
	M	36	.3	90	.7	126	1.0
LRM2 md	F	36	.5	40	.5	76	1.0
	M	42	.3	84	.7	126	1.0
LRM2 bl	F	39	.5	37	.5	76	1.0
	M	47	.4	79	.6	126	1.0
LRM3 md	F	20	.3	56	.7	76	1.0
	M	30	.2	96	.8	126	1.0
LRM3 bl	F	22	.3	54	.7	76	1.0
	M	37	.3	89	.7	126	1.0

Appendix B

ROC results for single-tooth regression logits (left side only)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULI1 BL	0.596	.0566400	.912	.641	.5435800	.692	.579
		.0742100	.895	.641	.5511100	.692	.596
		.0867600	.877	.641	.5586400	.692	.614
		.0942900	.860	.641	.5711900	.718	.614
		.1043300	.842	.641	.5862500	.718	.632
		.1143700	.825	.641	.5962900	.718	.649
		.1193900	.807	.641	.6213900	.744	.667
		.1294300	.789	.641			
		.1394700	.789	.615			
		.1545300	.789	.590			
		.1695900	.754	.590			
		.1921800	.737	.590			
		.2398700	.737	.564			
		.2725000	.719	.564			
		.2976000	.702	.564			
		.3277200	.684	.538			
		.3402700	.667	.513			
		.3452900	.649	.513			
		.3553300	.614	.513			
ULI2 BL	0.555	.4023200	.758	.667	.5119300	.615	.565
		.4071700	.742	.667	.5226000	.641	.581
		.4149300	.742	.641	.5313300	.667	.581
		.4226900	.742	.615	.5352100	.718	.581
		.4294800	.726	.615	.5410300	.718	.613
		.4353000	.726	.590	.5449100	.718	.629
		.4382100	.726	.564	.5478200	.718	.661
		.4411200	.710	.538	.5507300	.744	.661
		.4459700	.694	.538	.5565500	.744	.677
		.4508200	.661	.538	.5681900	.769	.694
		.4547000	.645	.538			
		.4576100	.629	.538			
		.4614900	.613	.538			

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULC BL	0.656	-.04087	.791	.680	.21500	.600	.328
		-.02363	.776	.680	.23225	.620	.358
		-.00638	.776	.660	.24088	.620	.373
		.01950	.761	.640	.24950	.620	.388
		.04825	.746	.640	.25813	.640	.388
		.05687	.731	.640	.26675	.660	.388
		.06262	.716	.620	.28400	.680	.388
		.07125	.716	.600	.31563	.680	.403
		.07987	.701	.600	.34438	.680	.418
		.08562	.701	.580	.37025	.680	.433
		.09425	.687	.580	.39325	.680	.448
		.10575	.687	.540	.40762	.680	.463
		.11725	.687	.520	.41913	.700	.463
		.12875	.687	.500	.42775	.700	.478
		.14025	.672	.500	.45938	.700	.493
		.15750	.672	.460	.49100	.700	.507
		.17763	.672	.440	.49963	.720	.507
		.19488	.672	.420	.50538	.760	.507
		.21500	.672	.400	.51400	.760	.522
		.23225	.642	.380	.52263	.760	.537
		.24088	.627	.380	.52838	.780	.537
		.24950	.612	.380	.54275	.800	.552
		.25813	.612	.360	.56575	.800	.567
		.26675	.612	.340	.58012	.820	.567
		.28400	.612	.320	.58875	.860	.567
					.61175	.860	.582
					.64625	.880	.582
					.66637	.900	.582
					.67787	.900	.597
					.69225	.920	.597

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULP1 MD+BL	0.757	-.70917	.943	.659	.30677	.707	.302
		-.68844	.925	.659	.32177	.707	.321
		-.64156	.925	.634	.33147	.707	.340
		-.60254	.925	.610	.34327	.732	.340
		-.58135	.925	.585	.35282	.756	.340
		-.49530	.906	.585	.35619	.780	.340
		-.38473	.906	.561	.35811	.780	.358
		-.31780	.887	.561	.36809	.780	.377
		-.29294	.868	.561	.38362	.805	.377
		-.29074	.868	.537	.39342	.805	.396
		-.26611	.849	.537	.40379	.805	.415
		-.21498	.830	.537	.41389	.829	.415
		-.17826	.830	.512	.43270	.829	.434
		-.15272	.811	.512	.45241	.829	.453
		-.11519	.811	.488	.50531	.829	.472
		-.08889	.792	.488	.55600	.829	.491
		-.08049	.792	.463	.57584	.829	.509
		-.07572	.792	.439	.60410	.829	.528
		-.06363	.774	.439	.69356	.829	.547
		-.04411	.755	.439	.80031	.854	.547
		-.03323	.736	.439	.83455	.878	.547
		-.01671	.717	.439	.84497	.878	.566
		.03674	.698	.439	.87001	.902	.566
		.12443	.698	.415	.96130	.927	.566
		.21067	.698	.390			
		.25114	.698	.366			
		.26072	.698	.341			
		.28182	.698	.317			
		.30677	.698	.293			
		.32177	.679	.293			
		.33147	.660	.293			
		.34327	.660	.268			
		.35282	.660	.244			
		.35619	.660	.220			
		.35811	.642	.220			
		.36809	.623	.220			
		.38362	.623	.195			

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULP2 MD+BL	0.643	.01784	.882	.667	.40467	.611	.412
		.02549	.863	.667	.42023	.611	.431
		.03008	.843	.667	.42890	.639	.431
		.06221	.843	.639	.46613	.639	.451
		.11346	.843	.611	.50540	.639	.471
		.14049	.824	.611	.52529	.639	.490
		.15375	.824	.583	.53574	.667	.490
		.16089	.824	.556	.54849	.667	.510
		.16395	.824	.528	.56277	.694	.510
		.17058	.804	.528	.57935	.694	.529
		.18257	.804	.500	.59949	.694	.549
		.20450	.784	.500	.60918	.694	.569
		.23178	.784	.472	.61505	.694	.588
		.25626	.765	.472	.62448	.694	.608
		.28431	.765	.444	.65457	.722	.608
		.30063	.745	.444	.69512	.722	.627
		.30140	.725	.444	.71552	.722	.647
		.30548	.706	.444	.73617	.750	.647
		.31848	.686	.444	.76116	.778	.647
		.34118	.667	.444	.79125	.778	.667
		.35903	.647	.444	.83486	.806	.667
		.37076	.627	.444			
		.37892	.608	.444			
ULM1 MD	0.659	-.03668	.837	.517	.53428	.621	.512
		.01212	.814	.517	.56600	.621	.535
		.06580	.791	.517	.61724	.655	.535
		.10728	.791	.483	.66360	.724	.535
		.14388	.767	.483	.67824	.724	.558
		.17560	.744	.483	.70264	.724	.581
		.19268	.721	.483	.74656	.724	.605
		.23904	.698	.483	.77584	.759	.605
		.27808	.674	.483	.78804	.793	.605
		.28296	.651	.483	.80756	.828	.605
		.29516	.628	.483	.82952	.828	.628
		.30736	.628	.448	.83928	.828	.651
					.85880	.862	.651
					.89052	.897	.651
					.91980	.931	.651
					.93932	.966	.674

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULM2 BL	0.591	-.16498	.913	.684	.27098	.605	.543
		-.12844	.891	.684	.27602	.605	.565
		-.07552	.891	.658	.29492	.632	.565
		-.04780	.870	.658	.31634	.632	.587
		-.04024	.848	.658	.32390	.632	.609
		-.03016	.848	.632	.33650	.632	.630
		-.01000	.826	.632	.35162	.658	.630
		.00386	.804	.632	.36422	.711	.630
		.00638	.804	.605	.38060	.711	.652
		.01520	.804	.579	.38942	.711	.674
		.02402	.783	.579	.39194	.711	.696
		.02906	.761	.579	.41462	.737	.696
		.03662	.739	.579			
		.04670	.739	.553			
		.05426	.717	.526			
		.05678	.717	.500			
		.05930	.674	.500			
		.08324	.652	.500			
		.12734	.630	.500			
		.16136	.609	.500			
ULM3 MD	0.628	14.17897	.875	.538	14.66290	.615	.417
		14.27236	.833	.538	14.69686	.615	.458
		14.32330	.792	.538	14.73082	.692	.458
		14.34240	.750	.538	14.78176	.692	.500
		14.40183	.667	.538	14.81572	.692	.542
		14.49947	.625	.538	14.86878	.692	.583
		14.55677	.625	.462	14.94519	.692	.625
					15.00250	.769	.625

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLI1 MD+BL	0.608	.0617850	.821	.650	.3702775	.625	.464
		.0643700	.804	.650	.3862225	.625	.482
		.0692900	.804	.625	.3907625	.650	.482
		.0731700	.786	.625	.3962225	.675	.482
		.0776950	.786	.600	.4095200	.675	.500
		.0835650	.768	.600	.4371625	.700	.500
		.0893025	.750	.600	.4618950	.700	.518
		.0932725	.732	.600	.4750825	.700	.536
		.0953800	.732	.575	.4852000	.700	.554
		.1080750	.714	.575	.5063700	.725	.554
		.1191000	.714	.550	.5251075	.750	.554
		.1224125	.696	.550	.5491050	.775	.554
		.1297150	.696	.525	.5711000	.775	.571
		.1346075	.679	.525	.5882225	.775	.589
		.1373525	.661	.525	.6155250	.775	.607
		.1422100	.661	.500	.6280750	.775	.625
		.1515100	.643	.500	.6317475	.775	.643
		.1671575	.625	.500	.6399800	.800	.643
		.1857275	.625	.475			
LLI2 MD+BL	0.519	.1670475	.632	.681	.2070750	.638	.561
		.1742500	.632	.660	.2105625	.638	.579
		.1747850	.614	.660	.2147650	.638	.596
		.1751925	.614	.638	.2169950	.638	.614
					.2191025	.638	.632
					.2208275	.660	.632
					.2246650	.681	.632
					.2306225	.702	.632
					.2371875	.723	.632
					.2433300	.723	.649
					.2465350	.723	.667
					.2478400	.723	.684

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLC MD+BL	0.737	-.2568200	.910	.625	.2487200	.607	.256
		-.2022075	.897	.625	.2882400	.607	.269
		-.1524700	.897	.607	.3285275	.607	.282
		-.1129800	.885	.607	.3323975	.607	.295
		-.0871850	.872	.607	.3359600	.607	.308
		-.0825075	.872	.589	.3496100	.607	.321
		-.0767550	.859	.589	.3633550	.625	.321
		-.0729450	.859	.571	.3647675	.643	.321
		-.0570000	.859	.554	.3721750	.643	.333
		-.0341575	.859	.536	.3831650	.643	.346
		-.0221275	.846	.536	.3872725	.661	.346
		-.0120400	.833	.536	.3880650	.679	.346
		-.0048850	.821	.536	.3940850	.696	.346
		.0011600	.808	.536	.4039800	.696	.359
		.0104750	.795	.536	.4083950	.714	.359
		.0217225	.795	.518	.4130325	.714	.372
		.0319100	.782	.518	.4242800	.732	.372
		.0398975	.782	.500	.4347700	.732	.385
		.0689225	.769	.500	.4487725	.732	.397
		.1122775	.769	.482	.4627350	.750	.397
		.1460300	.769	.464	.4780950	.750	.410
		.1619850	.756	.464	.4989750	.768	.410
		.1685850	.756	.446	.5094600	.786	.410
		.1759575	.744	.446	.5204050	.786	.423
		.1946275	.744	.429	.5332575	.786	.436
		.2294650	.744	.411	.5434100	.786	.449
		.2487200	.744	.393	.5543600	.786	.462
		.2882400	.731	.393	.5782425	.804	.462
		.3285275	.718	.393	.6007525	.804	.474
		.3323975	.705	.393	.6416350	.804	.487
		.3359600	.692	.393	.6998150	.804	.500
		.3496100	.679	.393	.7203825	.821	.500
		.3633550	.679	.375	.7242175	.821	.513
		.3647675	.679	.357	.7631975	.839	.513
		.3721750	.667	.357	.7991650	.839	.526
		.3831650	.654	.357	.8180975	.857	.526
		.3872725	.654	.339	.8501650	.857	.538
		.3880650	.654	.321	.8633300	.857	.551
		.3940850	.654	.304	.8696525	.857	.564
		.4039800	.641	.304	.8838975	.857	.577
		.4083950	.641	.286	.8921175	.857	.590
		.4130325	.628	.286	.9085825	.875	.590
		.4242800	.628	.268	.9582750	.893	.590
		.4347700	.615	.268			
		.4487725	.603	.268			
		.4627350	.603	.250			

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLP1 BL	0.629	5.6638400	.845	.673	5.8820800	.615	.333
		5.6691200	.833	.673	5.8873600	.615	.345
		5.6744000	.821	.673	5.8926400	.615	.357
		5.6832000	.821	.654	5.8979200	.615	.381
		5.6902400	.810	.654	5.9032000	.615	.393
		5.7025600	.810	.635	5.9102400	.615	.405
		5.7148800	.798	.635	5.9172800	.635	.405
		5.7254400	.774	.615	5.9243200	.635	.429
		5.7430400	.774	.596	5.9313600	.635	.440
		5.7553600	.774	.577	5.9507200	.635	.452
		5.7800000	.750	.558	5.9771200	.654	.452
		5.8028800	.750	.519	5.9894400	.654	.476
		5.8064000	.738	.519	5.9929600	.654	.488
		5.8099200	.738	.500	6.0017600	.654	.500
		5.8134400	.738	.481	6.0105600	.654	.512
		5.8169600	.738	.462	6.0140800	.654	.524
		5.8275200	.738	.442	6.0211200	.673	.524
		5.8398400	.714	.442	6.0369600	.673	.536
		5.8504000	.690	.442	6.0510400	.673	.548
		5.8662400	.679	.442	6.0580800	.673	.560
		5.8768000	.667	.423	6.0633600	.692	.560
		5.8820800	.667	.385	6.0721600	.692	.571
		5.8873600	.655	.385	6.0844800	.712	.571
		5.8926400	.643	.385	6.1038400	.750	.571
		5.8979200	.619	.385	6.1196800	.750	.583
		5.9032000	.607	.385	6.1284800	.750	.595
					6.1372800	.769	.595
					6.1425600	.808	.595
					6.1478400	.808	.607
					6.1566400	.808	.619
					6.1672000	.808	.631
					6.1724800	.808	.643
					6.1848000	.827	.643
					6.1988800	.827	.655
					6.2076800	.846	.655

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLP2 MD+BL	0.675	-.16518750	.908	.681	.36033750	.638	.446
		-.13788750	.892	.681	.38422500	.638	.462
		-.10717500	.892	.660	.40128750	.660	.462
		-.09352500	.892	.638	.42176250	.660	.477
		-.07987500	.862	.617	.44906250	.660	.492
		-.05940000	.831	.596	.47636250	.660	.508
		-.03551250	.800	.553	.49001250	.681	.508
		-.01162500	.800	.532	.50707500	.702	.508
		.01226250	.785	.532	.52413750	.702	.523
		.04980000	.769	.532	.53778750	.723	.523
		.08733750	.769	.511	.55826250	.723	.538
		.10098750	.754	.511	.57191250	.745	.538
		.12487500	.754	.489	.57873750	.766	.538
		.15217500	.738	.489	.58897500	.766	.554
		.16241250	.723	.489	.60945000	.787	.569
		.16923750	.708	.489	.62651250	.830	.569
		.17606250	.708	.468	.64357500	.851	.569
		.18630000	.692	.468	.66063750	.851	.585
		.19653750	.677	.468	.67428750	.872	.600
		.20677500	.662	.468	.68793750	.872	.615
		.21701250	.662	.447	.69476250	.872	.631
		.23748750	.662	.426	.70841250	.872	.646
		.26137500	.631	.426	.72206250	.872	.662
		.27161250	.631	.404			
LLM1 MD+BL	0.658	-.94600	1.000	.625	-.51835	.600	.269
		-.92252	.962	.625	-.51163	.600	.308
		-.90027	.923	.625	-.49732	.600	.346
		-.85502	.885	.625	-.48407	.625	.346
		-.81722	.846	.625	-.46940	.650	.346
		-.79127	.846	.600	-.45482	.650	.385
		-.75911	.846	.575	-.44148	.650	.423
		-.73539	.808	.575	-.38948	.650	.462
		-.71495	.808	.550	-.33871	.650	.500
		-.69398	.808	.525	-.32091	.650	.538
		-.67264	.808	.500	-.29761	.675	.538
		-.66071	.769	.500	-.27368	.700	.538
		-.65093	.769	.475	-.25404	.700	.577
		-.61141	.769	.450	-.20990	.725	.577
		-.55331	.731	.450	-.17078	.750	.577
		-.52584	.731	.425			
		-.51835	.731	.400			
		-.51163	.692	.400			
		-.49732	.654	.400			
		-.48407	.654	.375			
		-.46940	.654	.350			

Appendix B (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLM2 MD+BL	0.632	-.05051	.844	.636	.35647	.606	.444
		-.03683	.822	.636	.37148	.606	.467
		-.01972	.822	.606	.38587	.606	.489
		-.00355	.800	.606	.42343	.606	.511
		.02820	.800	.576	.46496	.606	.533
		.05730	.778	.576	.47286	.636	.533
		.07493	.778	.545	.47567	.636	.556
		.11568	.778	.515	.48717	.667	.556
		.15355	.756	.515	.49943	.667	.578
		.17736	.733	.515	.52318	.697	.578
		.18975	.711	.515	.54449	.727	.578
		.19351	.689	.515	.55051	.727	.600
		.20005	.667	.515	.57270	.758	.600
		.22428	.644	.515	.59245	.788	.600
		.25245	.622	.515	.60820	.788	.622
		.28369	.622	.485	.62484	.818	.622
		.30839	.622	.455	.63088	.848	.622
LLM3 MD+BL	0.665	.28638	.919	.600	.71811	.600	.405
		.30120	.892	.600	.73796	.600	.432
		.32541	.865	.600	.75036	.650	.432
		.35794	.865	.550	.76378	.700	.432
		.37774	.838	.550	.81123	.750	.432
		.38363	.811	.550	.84964	.750	.459
		.39729	.784	.550	.86794	.750	.486
		.42311	.784	.500	.88781	.750	.514
		.44163	.757	.500	.89489	.750	.541
		.45665	.730	.500	.89923	.800	.541
		.50826	.703	.500			
		.55329	.676	.500			
		.57428	.676	.450			

Appendix C

ROC results for individual tooth measurements (left side only)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULI1 MD	0.518	7.9850	.830	.686	8.6225	.600	.660
		8.0075	.809	.686	8.6350	.600	.681
		8.0150	.787	.686	8.6550	.600	.702
		8.0275	.787	.657	8.6875	.629	.702
		8.0475	.766	.657	8.7125	.657	.702
		8.0650	.745	.657	8.7225	.714	.723
		8.0850	.723	.657	8.7375	.714	.766
		8.1075	.681	.657	8.7550	.743	.766
		8.1450	.660	.657	8.7775	.800	.766
		8.1775	.617	.657	8.7975	.829	.766
		8.1900	.617	.629	8.8025	.829	.787
		8.2050	.617	.600			
ULI1 BL	0.596	6.6200	.912	.692	7.1350	.641	.579
		6.6600	.912	.641	7.1450	.692	.579
		6.6775	.895	.641	7.1525	.692	.596
		6.6900	.877	.641	7.1600	.692	.614
		6.6975	.860	.641	7.1725	.718	.614
		6.7075	.842	.641	7.1875	.718	.632
		6.7175	.825	.641	7.1975	.718	.649
		6.7225	.807	.641	7.2225	.744	.667
		6.7325	.789	.641	7.2475	.744	.684
		6.7425	.789	.615			
		6.7575	.789	.590			
		6.7725	.754	.590			
		6.7950	.737	.590			
		6.8425	.737	.564			
		6.8750	.719	.564			
		6.9000	.702	.564			
		6.9300	.684	.538			
		6.9425	.667	.513			
		6.9475	.649	.513			
		6.9575	.614	.513			
		6.9700	.614	.487			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULI2 MD	0.547	6.5775	.729	.686	6.9125	.600	.441
		6.5825	.712	.686	6.9225	.600	.458
		6.5975	.695	.686	6.9300	.600	.475
		6.6200	.678	.686	6.9425	.600	.492
		6.6350	.678	.657	6.9550	.600	.525
		6.6450	.678	.629	6.9725	.600	.542
		6.6625	.678	.600	7.0000	.600	.559
		6.6800	.661	.600	7.0275	.629	.559
		6.6975	.661	.571	7.0425	.629	.576
		6.7200	.661	.543	7.0500	.686	.576
		6.7350	.644	.543	7.0725	.714	.593
		6.7550	.627	.543	7.0925	.714	.610
		6.7850	.610	.543	7.0975	.714	.627
					7.1025	.714	.644
					7.1150	.714	.661
					7.1325	.743	.661
					7.1500	.743	.678
					7.1675	.771	.695
ULI2 BL	0.555	6.1325	.758	.692	6.4225	.615	.565
		6.1400	.758	.667	6.4500	.641	.581
		6.1525	.742	.667	6.4725	.667	.581
		6.1725	.742	.641	6.4825	.718	.581
		6.1925	.742	.615	6.4975	.718	.613
		6.2100	.726	.615	6.5075	.718	.629
		6.2250	.726	.590	6.5150	.718	.661
		6.2325	.726	.564	6.5225	.744	.661
		6.2400	.710	.538	6.5375	.744	.677
		6.2525	.694	.538	6.5675	.769	.694
		6.2650	.661	.538			
		6.2750	.645	.538			
		6.2825	.629	.538			
		6.2925	.613	.538			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULC MD	0.591	7.4175	.746	.688	7.7525	.604	.429
		7.4550	.746	.667	7.7575	.604	.444
		7.4625	.730	.667	7.7625	.646	.460
		7.4875	.714	.667	7.7700	.646	.476
		7.5250	.698	.667	7.7775	.646	.492
		7.5525	.683	.667	7.7925	.667	.524
		7.5700	.683	.646	7.8125	.688	.524
		7.5850	.683	.625	7.8250	.708	.524
		7.5975	.683	.604	7.8325	.708	.540
		7.6025	.683	.583	7.8400	.708	.556
		7.6175	.667	.583	7.8500	.729	.556
		7.6350	.667	.542	7.8575	.750	.556
		7.6450	.651	.542	7.8625	.771	.571
		7.6600	.651	.521	7.8675	.771	.587
		7.6800	.635	.521	7.8775	.771	.603
		7.6950	.619	.521	7.8875	.792	.619
		7.7100	.603	.521	7.8950	.833	.619
					7.9025	.833	.635
					7.9075	.833	.651
					7.9200	.833	.667
					7.9325	.833	.683
					7.9575	.854	.683
					8.0000	.854	.698

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULC BL	0.656	7.6575	.791	.680	7.8800	.600	.328
		7.6725	.776	.680	7.8950	.620	.358
		7.6875	.776	.660	7.9025	.620	.373
		7.7100	.761	.640	7.9100	.620	.388
		7.7350	.746	.640	7.9175	.640	.388
		7.7425	.731	.640	7.9250	.660	.388
		7.7475	.716	.620	7.9400	.680	.388
		7.7550	.716	.600	7.9675	.680	.403
		7.7625	.701	.600	7.9925	.680	.418
		7.7675	.701	.580	8.0150	.680	.433
		7.7750	.687	.580	8.0350	.680	.448
		7.7850	.687	.540	8.0475	.680	.463
		7.7950	.687	.520	8.0575	.700	.463
		7.8050	.687	.500	8.0650	.700	.478
		7.8150	.672	.500	8.0925	.700	.493
		7.8300	.672	.460	8.1200	.700	.507
		7.8475	.672	.440	8.1275	.720	.507
		7.8625	.672	.420	8.1325	.760	.507
		7.8800	.672	.400	8.1400	.760	.522
		7.8950	.642	.380	8.1475	.760	.537
		7.9025	.627	.380	8.1525	.780	.537
		7.9100	.612	.380	8.1650	.800	.552
		7.9175	.612	.360	8.1850	.800	.567
		7.9250	.612	.340	8.1975	.820	.567
		7.9400	.612	.320	8.2050	.860	.567
					8.2250	.860	.582
					8.2550	.880	.582
					8.2725	.900	.582
					8.2825	.900	.597
					8.2950	.920	.597
					8.3075	.920	.612
					8.3200	.920	.642
					8.3275	.920	.657
					8.3325	.920	.672
					8.3425	.920	.687

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULP1 MD	0.609	6.7825	.793	.698	7.0800	.605	.345
		6.7875	.776	.698	7.0925	.605	.362
		6.7925	.759	.674	7.1200	.605	.379
		6.8000	.741	.674	7.1425	.628	.379
		6.8075	.741	.651	7.1475	.628	.397
		6.8225	.741	.628	7.1550	.651	.397
		6.8725	.741	.605	7.1625	.674	.414
		6.9200	.724	.605	7.1825	.698	.414
		6.9550	.707	.605	7.2100	.698	.431
		6.9850	.690	.605	7.2375	.721	.431
		6.9925	.690	.581	7.2575	.721	.448
		7.0025	.690	.558	7.2700	.744	.500
		7.0150	.690	.535	7.3000	.767	.517
		7.0300	.690	.512	7.3225	.767	.534
		7.0425	.672	.488	7.3325	.767	.552
		7.0525	.672	.442	7.3450	.767	.586
		7.0650	.672	.419	7.3700	.767	.603
		7.0725	.655	.419	7.3925	.767	.621
		7.0800	.655	.395	7.4000	.791	.621
		7.0925	.638	.395	7.4225	.791	.638
		7.1200	.621	.395	7.4500	.791	.672
		7.1425	.621	.372	7.4675	.814	.672
		7.1475	.603	.372	7.4800	.814	.690
		7.1550	.603	.349			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULP1 BL	0.735	8.7500	.944	.698	9.2350	.605	.352
		8.7875	.944	.674	9.2425	.628	.352
		8.8100	.944	.651	9.2625	.651	.370
		8.8250	.926	.628	9.2950	.698	.389
		8.8350	.926	.605	9.3225	.721	.389
		8.8750	.926	.581	9.3375	.721	.407
		8.9325	.907	.581	9.3425	.721	.426
		8.9575	.889	.581	9.3525	.744	.426
		8.9625	.870	.581	9.3675	.767	.426
		8.9675	.870	.558	9.3875	.767	.444
		8.9750	.852	.558	9.4100	.767	.463
		8.9850	.833	.558	9.4300	.767	.481
		9.0000	.833	.512	9.4425	.791	.481
		9.0250	.815	.512	9.4475	.791	.500
		9.0450	.796	.488	9.4750	.814	.519
		9.0550	.796	.465	9.5150	.837	.519
		9.0825	.778	.465	9.5450	.860	.519
		9.1125	.759	.465	9.5625	.884	.519
		9.1300	.722	.465	9.5675	.907	.519
		9.1650	.704	.442	9.6000	.907	.537
		9.2000	.685	.419	9.6550	.907	.556
		9.2150	.667	.419	9.6825	.907	.574
		9.2250	.648	.419	9.7325	.907	.593
		9.2350	.648	.395	9.8000	.930	.593
		9.2425	.648	.372	9.8350	.930	.611
		9.2625	.630	.349	9.8700	.930	.630
		9.2950	.611	.302	9.9000	.953	.630
		9.3225	.611	.279	9.9200	.953	.648
					9.9325	.953	.667
					9.9375	.953	.685

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULP2 MD	0.551	6.3925	.754	.694	6.6225	.611	.421
		6.4050	.737	.694	6.6275	.611	.439
		6.4225	.719	.667	6.6525	.639	.439
		6.4450	.702	.667	6.6800	.639	.456
		6.4625	.684	.639	6.6925	.639	.491
		6.4750	.667	.639	6.7025	.639	.509
		6.4850	.667	.583	6.7150	.639	.526
		6.4950	.649	.583	6.7275	.639	.544
		6.5075	.649	.556	6.7350	.639	.561
		6.5225	.632	.556	6.7425	.639	.579
		6.5325	.632	.500	6.7525	.639	.596
		6.5475	.614	.500	6.7625	.639	.614
		6.5650	.614	.472	6.7925	.667	.614
		6.5800	.614	.444	6.8325	.667	.632
					6.8475	.694	.632
					6.8600	.694	.649
					6.8750	.694	.667
					6.8900	.750	.667
ULP2 BL	0.629	8.7250	.849	.649	9.2275	.622	.509
		8.7350	.830	.649	9.2500	.622	.528
		8.7425	.811	.649	9.2800	.622	.547
		8.7625	.792	.649	9.2975	.622	.566
		8.8000	.774	.595	9.3125	.622	.585
		8.8250	.774	.568	9.3250	.649	.585
		8.8325	.774	.541	9.3350	.676	.585
		8.8375	.755	.541	9.3600	.703	.585
		8.8500	.736	.541	9.3925	.730	.585
		8.8675	.736	.514	9.4175	.730	.604
		8.8825	.736	.486	9.4400	.757	.604
		8.8925	.717	.486	9.4600	.784	.604
		8.8975	.698	.486	9.4725	.811	.604
		8.9400	.679	.486	9.4800	.811	.623
		8.9925	.660	.486	9.4900	.838	.623
		9.0150	.642	.486	9.5075	.838	.642
		9.0275	.604	.486	9.5350	.865	.642
					9.5525	.865	.660
					9.5575	.865	.679
					9.5700	.865	.698
					9.6200	.919	.698

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULM1 MD	0.659	9.6125	.837	.655	10.2800	.621	.512
		9.6375	.837	.621	10.3125	.621	.535
		9.6525	.837	.586	10.3650	.655	.535
		9.6675	.837	.552	10.4125	.724	.535
		9.6950	.837	.517	10.4275	.724	.558
		9.7450	.814	.517	10.4525	.724	.581
		9.8000	.791	.517	10.4975	.724	.605
		9.8425	.791	.483	10.5275	.759	.605
		9.8800	.767	.483	10.5400	.793	.605
		9.9125	.744	.483	10.5600	.828	.605
		9.9300	.721	.483	10.5825	.828	.628
		9.9775	.698	.483	10.5925	.828	.651
		10.0175	.674	.483	10.6125	.862	.651
		10.0225	.651	.483	10.6450	.897	.651
		10.0350	.628	.483	10.6750	.931	.651
		10.0475	.628	.448	10.6950	.966	.674
		10.0550	.605	.448	10.7150	.966	.698
ULM1 BL	0.58	10.6200	.833	.697	11.0800	.606	.452
		10.6350	.810	.697	11.0950	.636	.476
		10.6550	.786	.697	11.1025	.636	.500
		10.6975	.786	.667	11.1075	.636	.524
		10.7275	.762	.667	11.1150	.636	.571
		10.7400	.762	.636	11.1225	.636	.595
		10.7600	.762	.606	11.1375	.636	.619
		10.7925	.762	.576	11.1700	.667	.619
		10.8175	.738	.576	11.2125	.667	.643
		10.8250	.714	.576	11.2425	.667	.667
		10.8375	.714	.545	11.2550	.697	.667
		10.8750	.714	.515	11.2725	.727	.690
		10.9375	.667	.515			
		10.9800	.643	.485			
		11.0000	.619	.485			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULM2 MD	0.571	9.3050	.816	.676	9.9525	.622	.510
		9.3725	.796	.676	9.9700	.649	.510
		9.4275	.796	.649	9.9850	.676	.510
		9.4400	.776	.649	10.0050	.676	.531
		9.4525	.735	.649	10.0475	.676	.551
		9.4625	.714	.649	10.0775	.676	.571
		9.4725	.694	.595	10.0825	.676	.592
		9.4925	.673	.595	10.0900	.676	.612
		9.5400	.653	.595	10.1000	.703	.633
		9.5750	.653	.568	10.1150	.730	.633
		9.5975	.612	.568	10.1325	.730	.653
		9.6450	.612	.541	10.1600	.757	.653
		9.6975	.612	.514	10.2025	.757	.673
					10.2300	.784	.673
					10.2425	.784	.694
					10.2675	.784	.714
					10.3075	.784	.735
					10.3400	.811	.755
					10.3750	.811	.776
					10.4025	.838	.776
					10.4125	.838	.796
ULM2 BL	0.591	10.5675	.913	.684	11.4325	.605	.543
		10.6400	.891	.684	11.4425	.605	.565
		10.7450	.891	.658	11.4800	.632	.565
		10.8000	.870	.658	11.5225	.632	.587
		10.8150	.848	.658	11.5375	.632	.609
		10.8350	.848	.632	11.5625	.632	.630
		10.8750	.826	.632	11.5925	.658	.630
		10.9025	.804	.632	11.6175	.711	.630
		10.9075	.804	.605	11.6500	.711	.652
		10.9250	.804	.579	11.6675	.711	.674
		10.9425	.783	.579	11.6725	.711	.696
		10.9525	.761	.579	11.7175	.737	.696
		10.9675	.739	.579			
		10.9875	.739	.553			
		11.0025	.717	.526			
		11.0075	.717	.500			
		11.0125	.674	.500			
		11.0600	.652	.500			
		11.1475	.630	.500			
		11.2150	.609	.500			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
ULM3 MD	0.656	8.1300	.957	.692	8.9775	.615	.391
		8.2300	.957	.615	9.0175	.615	.435
		8.3350	.913	.615	9.0575	.692	.435
		8.4075	.913	.538	9.1175	.692	.478
		8.5175	.870	.538	9.1575	.692	.522
		8.5775	.826	.538	9.2200	.692	.565
		8.6000	.783	.538	9.3100	.692	.609
		8.6700	.696	.538	9.3775	.769	.609
		8.7850	.652	.538	9.4325	.769	.652
		8.8525	.652	.462			
		8.9050	.609	.462			
		8.9775	.609	.385			
ULM3 BL	0.665	10.3150	.958	.692	10.8475	.615	.333
		10.3725	.917	.692	10.8950	.615	.375
		10.4250	.917	.615	10.9950	.615	.417
		10.5325	.917	.538	11.0575	.692	.417
		10.6700	.875	.538	11.1100	.692	.458
		10.7150	.833	.538	11.1675	.692	.500
		10.7350	.792	.538	11.1950	.769	.500
		10.7725	.750	.538	11.2125	.769	.542
		10.8125	.708	.538	11.2425	.769	.583
		10.8375	.667	.462	11.2950	.769	.625
		10.8475	.667	.385	11.3225	.769	.667
		10.8950	.625	.385			
LLI1 MD	0.469	4.9100	.780	.780	5.3225	.610	.610
		4.9325	.763	.780	5.3325	.634	.610
		4.9425	.746	.780	5.3475	.634	.627
		4.9550	.729	.780	5.3575	.659	.627
		4.9675	.729	.756	5.3625	.707	.661
		4.9750	.712	.756	5.3725	.707	.678
		4.9850	.695	.756	5.3950	.732	.678
		5.0150	.661	.756	5.4250	.732	.695
		5.0550	.627	.756			
		5.0750	.627	.732			
		5.0825	.593	.732			
		5.1000	.576	.732			
		5.1175	.559	.732			
		5.1325	.559	.707			
		5.1475	.542	.707			
		5.1550	.542	.683			
		5.1650	.525	.634			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLI1 BL	0.593	5.3225	.780	.689	5.6050	.600	.424
		5.3300	.763	.689	5.6125	.600	.458
		5.3375	.746	.689	5.6175	.600	.492
		5.3450	.695	.644	5.6250	.600	.508
		5.3550	.678	.644	5.6325	.622	.508
		5.3625	.661	.622	5.6575	.622	.525
		5.3725	.661	.600	5.6825	.622	.542
		5.3875	.661	.578	5.6875	.622	.559
		5.4100	.644	.578	5.6925	.644	.576
		5.4275	.644	.556	5.7050	.667	.576
		5.4375	.644	.533	5.7175	.689	.593
		5.4525	.644	.511	5.7250	.689	.610
		5.4775	.627	.511	5.7325	.711	.610
		5.5125	.610	.489	5.7475	.733	.610
		5.5450	.610	.467	5.7650	.756	.610
					5.7725	.778	.644
					5.7775	.778	.661
					5.7875	.800	.661
					5.7975	.800	.678
					5.8050	.822	.678
					5.8200	.844	.678
					5.8350	.867	.678
					5.8475	.889	.678
					5.8575	.889	.695
LLI2 MD	0.514	5.5725	.776	.688	5.9900	.604	.655
		5.5825	.759	.688	6.0075	.604	.672
		5.6075	.759	.667	6.0200	.604	.690
		5.6275	.759	.646	6.0300	.646	.690
		5.6375	.759	.625			
		5.6525	.741	.625			
		5.6650	.724	.625			
		5.6750	.724	.604			
LLI2 BL	0.521	5.8750	.627	.688	6.1025	.604	.576
		5.8850	.627	.646	6.1150	.625	.576
		5.8950	.627	.625	6.1325	.625	.593
		5.9050	.627	.604	6.1525	.646	.610
		5.9150	.627	.583	6.1700	.646	.627
		5.9275	.610	.563	6.1875	.646	.661
		5.9375	.610	.542	6.2050	.667	.661
					6.2300	.688	.661
					6.2550	.729	.661
					6.2650	.750	.678

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLC MD	0.718	6.4725	.863	.679	6.7825	.607	.275
		6.4875	.863	.661	6.7925	.607	.288
		6.5025	.863	.643	6.8025	.607	.313
		6.5075	.850	.643	6.8125	.625	.313
		6.5150	.838	.643	6.8275	.643	.313
		6.5350	.838	.625	6.8425	.643	.325
		6.5538	.838	.607	6.8525	.643	.338
		6.5638	.838	.589	6.8675	.661	.363
		6.5825	.838	.571	6.8950	.679	.363
		6.5975	.838	.554	6.9200	.696	.388
		6.6050	.825	.554	6.9275	.696	.400
		6.6200	.813	.554	6.9325	.714	.413
		6.6450	.800	.554	6.9375	.714	.438
		6.6625	.800	.536	6.9425	.750	.450
		6.6675	.800	.518	6.9475	.768	.463
		6.6800	.800	.500	6.9525	.786	.475
		6.6950	.800	.482	6.9600	.786	.488
		6.7050	.788	.482	6.9700	.786	.500
		6.7150	.788	.464	6.9775	.786	.513
		6.7250	.775	.464	6.9850	.804	.513
		6.7325	.763	.429	7.0000	.821	.513
		6.7450	.750	.429	7.0125	.821	.525
		6.7600	.738	.429	7.0175	.839	.538
		6.7675	.738	.411	7.0250	.839	.550
		6.7725	.725	.411	7.0375	.839	.563
		6.7825	.725	.393	7.0525	.839	.575
		6.7925	.713	.393	7.0625	.857	.600
		6.8025	.688	.393	7.0700	.875	.600
		6.8125	.688	.375	7.0775	.875	.613
		6.8275	.688	.357	7.0875	.893	.613
		6.8425	.675	.357	7.1000	.893	.625
		6.8525	.663	.357	7.1125	.893	.638
		6.8675	.638	.339	7.1225	.893	.663
		6.8950	.638	.321	7.1325	.911	.663
		6.9200	.613	.304	7.1450	.911	.675
		6.9275	.600	.304	7.1550	.911	.688

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLC BL	0.69	7.11000	.847	.684	7.37250	.614	.259
		7.12250	.835	.684	7.39250	.614	.271
		7.13250	.835	.667	7.40500	.614	.306
		7.14750	.824	.667	7.41250	.632	.306
		7.15750	.824	.649	7.42500	.632	.318
		7.16500	.812	.649	7.43750	.632	.329
		7.17500	.812	.632	7.44500	.649	.329
		7.18500	.812	.614	7.45250	.667	.329
		7.20500	.812	.596	7.46500	.684	.329
		7.22800	.812	.579	7.48000	.684	.341
		7.24800	.812	.561	7.50000	.702	.353
		7.28000	.800	.561	7.51750	.702	.365
		7.30500	.800	.544	7.52250	.702	.376
		7.31250	.788	.509	7.52750	.719	.388
		7.32000	.776	.509	7.53750	.719	.400
		7.33250	.753	.491	7.54750	.737	.412
		7.34500	.753	.421	7.55750	.737	.435
		7.35500	.741	.404	7.56750	.737	.447
		7.37250	.741	.386	7.57250	.737	.459
		7.39250	.729	.386	7.57750	.754	.459
		7.40500	.694	.386	7.59000	.754	.471
		7.41250	.694	.368	7.60500	.754	.494
		7.42500	.682	.368	7.61500	.772	.506
		7.43750	.671	.368	7.62750	.789	.529
		7.44500	.671	.351	7.63750	.789	.553
		7.45250	.671	.333	7.64500	.789	.565
		7.46500	.671	.316	7.65750	.789	.576
		7.48000	.659	.316	7.67750	.789	.600
		7.50000	.647	.298	7.69500	.789	.612
		7.51750	.635	.298	7.70250	.789	.624
		7.52250	.624	.298	7.71250	.807	.624
		7.52750	.612	.281	7.72500	.807	.647
		7.53750	.600	.281	7.73500	.842	.647
					7.74500	.842	.659
					7.75500	.860	.671
					7.77750	.860	.682
					7.79750	.860	.694

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLP1 MD	0.55	6.65750	.802	.698	7.13250	.604	.519
		6.67500	.790	.698	7.14500	.623	.531
		6.68250	.778	.698	7.15500	.642	.531
		6.70000	.765	.698	7.16250	.642	.556
		6.71750	.753	.660	7.17000	.642	.568
		6.72250	.741	.660	7.17750	.642	.580
		6.72750	.741	.642	7.18250	.642	.605
		6.75000	.741	.623	7.18750	.660	.605
		6.78000	.728	.604	7.19500	.679	.630
		6.79500	.716	.604	7.20750	.679	.642
		6.81750	.704	.604	7.22250	.679	.654
		6.85000	.691	.585	7.23250	.679	.679
		6.87250	.691	.566	7.23750	.679	.691
		6.89250	.679	.566			
		6.91500	.667	.566			
		6.92750	.667	.547			
		6.93250	.654	.528			
		6.93750	.642	.528			
		6.94500	.630	.509			
		6.95750	.630	.491			
		6.97750	.617	.491			
		6.99500	.605	.491			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLP1 BL	0.636	7.32250	.855	.692	7.64500	.615	.325
		7.33500	.855	.673	7.65250	.615	.337
		7.34250	.843	.673	7.66000	.615	.349
		7.35000	.831	.673	7.66750	.615	.373
		7.36250	.831	.654	7.67500	.615	.386
		7.37250	.819	.654	7.68500	.615	.398
		7.39000	.819	.635	7.69500	.635	.398
		7.40750	.807	.635	7.70500	.635	.422
		7.42250	.783	.615	7.71500	.635	.434
		7.44750	.783	.596	7.74250	.635	.446
		7.46500	.783	.577	7.78000	.654	.446
		7.50000	.759	.558	7.79750	.654	.470
		7.53250	.759	.519	7.80250	.654	.482
		7.53750	.747	.519	7.81500	.654	.494
		7.54250	.747	.500	7.82750	.654	.506
		7.54750	.747	.481	7.83250	.654	.518
		7.55250	.747	.462	7.84250	.673	.518
		7.56750	.747	.442	7.86500	.673	.530
		7.58500	.723	.442	7.88500	.673	.542
		7.60000	.699	.442	7.89500	.673	.554
		7.62250	.687	.442	7.90250	.692	.554
		7.63750	.675	.423	7.91500	.692	.566
		7.64500	.675	.385	7.93250	.712	.566
		7.65250	.663	.385	7.96000	.750	.566
		7.66000	.651	.385	7.98250	.750	.578
		7.66750	.627	.385	7.99500	.750	.590
		7.67500	.614	.385	8.00750	.769	.590
		7.68500	.602	.385	8.01500	.808	.590
		7.69500	.602	.365	8.02250	.808	.602
					8.03500	.808	.614
					8.05000	.808	.627
					8.05750	.808	.639
					8.07500	.827	.639
					8.09500	.827	.651
					8.10750	.846	.651
					8.13250	.846	.663
					8.16000	.846	.675
					8.17500	.846	.687
					8.19000	.846	.699

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLP2 MD	0.677	7.02000	.692	.458	7.08250	.604	.369
		7.02750	.677	.458	7.09250	.604	.385
		7.03500	.662	.458	7.10750	.604	.400
		7.04250	.662	.438	7.11750	.604	.415
		7.05750	.662	.417	7.12750	.604	.431
		7.07500	.631	.417	7.14750	.646	.446
		7.08250	.631	.396	7.16500	.646	.462
		7.09250	.615	.396	7.17750	.667	.462
		7.10750	.600	.396	7.19250	.667	.477
					7.21250	.667	.492
					7.23250	.667	.508
					7.24250	.688	.508
					7.25500	.708	.508
					7.26750	.708	.523
					7.27750	.729	.523
					7.29250	.729	.538
					7.30250	.750	.538
					7.30750	.771	.538
					7.31500	.771	.554
					7.33000	.792	.569
					7.34250	.833	.569
					7.35500	.854	.569
					7.36750	.854	.585
					7.37750	.875	.600
					7.38750	.875	.615
					7.39250	.875	.631
					7.40250	.875	.646
					7.41250	.875	.662
					7.42000	.875	.677

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLP2 BL	0.656	7.7550	.913	.681	8.2125	.617	.362
		7.7900	.899	.681	8.2175	.638	.377
		7.8050	.899	.660	8.2225	.638	.406
		7.8150	.855	.660	8.2400	.638	.420
		7.8300	.841	.660	8.2625	.638	.435
		7.8475	.826	.660	8.2850	.660	.435
		7.8575	.826	.638	8.3025	.681	.435
		7.8650	.826	.617	8.3075	.681	.449
		7.8825	.812	.596	8.3125	.681	.464
		7.9025	.797	.596	8.3300	.681	.478
		7.9125	.797	.574	8.3475	.681	.507
		7.9225	.797	.553	8.3525	.702	.507
		7.9450	.783	.553	8.3600	.702	.522
		7.9900	.768	.553	8.3750	.702	.536
		8.0350	.768	.532	8.3975	.723	.536
		8.0525	.754	.532	8.4175	.745	.536
		8.0675	.739	.532	8.4425	.745	.551
		8.0825	.739	.489	8.4650	.745	.580
		8.0950	.739	.468	8.4750	.766	.580
		8.1075	.739	.447	8.4950	.766	.594
		8.1150	.710	.447	8.5225	.766	.623
		8.1250	.681	.447	8.5425	.766	.638
		8.1325	.667	.447	8.5550	.766	.667
		8.1475	.652	.447	8.5650	.766	.681
		8.1700	.638	.447	8.6075	.787	.681
		8.1875	.638	.426	8.6500	.809	.681
		8.2025	.638	.404	8.6600	.809	.696
		8.2125	.638	.383			
		8.2175	.623	.362			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLM1 MD	0.602	10.82750	.818	.680	11.04500	.600	.303
		10.83250	.818	.640	11.16000	.640	.303
		10.83750	.788	.640	11.18250	.640	.333
		10.84250	.788	.600	11.18750	.640	.364
		10.85000	.788	.560	11.19500	.640	.394
		10.86250	.758	.560	11.21000	.640	.424
		10.87750	.727	.560	11.26000	.640	.455
		10.88750	.727	.520	11.31750	.640	.485
		10.89750	.697	.520	11.34000	.680	.485
		10.92250	.697	.480	11.35500	.680	.515
		10.94500	.697	.440	11.36750	.720	.515
		11.04500	.697	.400	11.37500	.720	.545
		11.16000	.697	.360	11.40500	.720	.576
		11.18250	.667	.360	11.45000	.720	.606
		11.18750	.636	.360	11.47250	.720	.636
		11.19500	.606	.360	11.48500	.760	.636
					11.52750	.760	.667
					11.58250	.800	.667
					11.61000	.800	.697
LLM1 BL	0.562	10.16000	.795	.679	10.58250	.607	.538
		10.17500	.795	.643	10.61250	.607	.564
		10.21000	.795	.571	10.63750	.643	.564
		10.25250	.769	.571	10.65250	.643	.590
		10.28750	.769	.536	10.68250	.679	.590
		10.31500	.744	.536	10.73250	.679	.615
		10.32250	.718	.536	10.76500	.679	.667
		10.33750	.692	.536	10.77500	.714	.667
		10.36250	.667	.536	10.79500	.714	.692
		10.38000	.641	.536			
		10.38750	.615	.536			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLM2 MD	0.622	10.2650	.826	.686	10.9175	.600	.522
		10.3050	.826	.657	10.9425	.600	.543
		10.3325	.826	.629	10.9600	.600	.565
		10.3450	.826	.600	10.9775	.629	.565
		10.3850	.804	.600	10.9975	.657	.565
		10.4450	.804	.543	11.0075	.686	.587
		10.4725	.783	.543	11.0150	.714	.609
		10.4825	.783	.514	11.0250	.714	.630
		10.5200	.783	.486	11.0650	.743	.630
		10.5625	.761	.486	11.1025	.743	.652
		10.6000	.739	.486	11.1250	.771	.652
		10.6275	.717	.486	11.1650	.800	.652
		10.6350	.696	.486	11.2050	.857	.652
		10.6550	.674	.486	11.2275	.857	.674
		10.6750	.652	.486	11.2350	.857	.696
		10.6900	.630	.486			
		10.7050	.609	.486			
LLM2 BL	0.618	9.8225	.857	.676	10.1525	.618	.449
		9.8400	.837	.676	10.1650	.647	.469
		9.8475	.816	.676	10.1750	.676	.469
		9.8650	.816	.647	10.1825	.706	.469
		9.8825	.796	.647	10.1900	.706	.490
		9.8875	.776	.647	10.1975	.706	.510
		9.8975	.776	.588	10.2050	.706	.531
		9.9150	.755	.588	10.2175	.735	.531
		9.9275	.755	.559	10.2375	.765	.531
		9.9325	.735	.559	10.2575	.765	.551
		9.9675	.735	.529	10.2675	.765	.571
		10.0100	.735	.500	10.2850	.765	.592
		10.0250	.714	.500	10.3125	.765	.612
		10.0325	.673	.500	10.3675	.765	.633
		10.0375	.653	.500	10.4150	.794	.633
		10.0450	.653	.471	10.4250	.794	.653
		10.0750	.653	.441	10.4400	.794	.673
		10.1025	.633	.441	10.4550	.794	.694
		10.1125	.612	.441			

Appendix C (continued)

Tooth	AUC	Males if ≥	Sensitivity	1-Specificity	Females if ≤	Sensitivity	1-Specificity
LLM3 MD	0.616	9.9075	.947	.650	11.0825	.600	.500
		9.9925	.947	.600	11.1400	.600	.526
		10.0575	.947	.550	11.1875	.600	.553
		10.2025	.921	.550	11.1950	.600	.579
		10.3425	.895	.550	11.2100	.600	.605
		10.3775	.868	.550	11.2250	.600	.632
		10.4350	.868	.500	11.2925	.650	.632
		10.5350	.842	.500	11.4500	.650	.658
		10.6050	.816	.500	11.5675	.700	.658
		10.6250	.789	.500	11.6025	.750	.658
		10.6375	.763	.500	11.6400	.750	.684
		10.6900	.737	.500			
		10.7425	.711	.500			
		10.7675	.684	.500			
		10.8100	.658	.500			
		10.8750	.632	.500			
		10.9300	.605	.500			
LLM3 BL	0.632	9.7550	.902	.650	10.4225	.600	.488
		9.8050	.878	.650	10.4425	.650	.488
		9.9275	.878	.600	10.4625	.650	.512
		10.0075	.878	.550	10.4775	.700	.512
		10.0125	.854	.500	10.4850	.700	.537
		10.0325	.829	.500	10.5100	.700	.561
		10.0650	.805	.500	10.5325	.750	.585
		10.0925	.780	.500	10.5425	.750	.610
		10.1125	.756	.500	10.5800	.750	.634
		10.1250	.732	.500	10.6525	.800	.659
		10.1525	.707	.500	10.6975	.800	.683
		10.1800	.683	.500			
		10.1975	.634	.500			
		10.2500	.610	.500			

Appendix D

TEM for Chiang Mai sample measurements

	ULI1 md	ULI1 bl	ULI2 md	ULI2 bl	ULC md	ULC bl	ULP1 md	ULP1 bl
Abs. TEM	0.0758	0.0126	0.0577	0.0794	0.0997	0.1133	0.0962	0.0494
VAV	6.395	6.783	7.281	6.5056	7.725	8.0108	7.0729	8.9988
Rel. TEM (%)	1.1853	0.1856	0.7925	1.2205	1.2906	1.4143	1.3601	0.549

	ULP2 md	ULP2 bl	ULM1 md	ULM1 bl	ULM2 md	ULM2 bl	ULM3 md	ULM3 bl
Abs. TEM	0.5205	0.674	0.1198	0.1861	0.0999	0.1997	0.0843	0.0695
VAV	6.7469	8.8463	9.9415	10.7933	9.4821	11.2013	9.005	10.5838
Rel. TEM (%)	7.7147	7.619	1.205	1.7242	1.0536	1.7828	0.9361	0.6567

	URI1 md	URI1 bl	URI2 md	URI2 bl	URC md	URC bl	URP1 md	URP1 bl
Abs. TEM	0.0703	0.102	0.0611	0.0832	0.1581	0.1715	0.0955	0.1141
VAV	8.4185	6.913	6.9856	6.22	7.6929	8.1336	7.0938	9.0633
Rel. TEM (%)	0.8351	1.4755	0.8747	1.3376	2.0551	2.1085	1.3462	1.2589

	URP2 md	URP2 bl	URM1 md	URM1 bl	URM2 md	URM2 bl	URM3 md	URM3 bl
Abs. TEM	0.0942	0.0654	0.1076	0.2871	0.1543	0.197	0.0532	0.0652
VAV	6.464	8.9894	11.0363	11.032	9.9575	10.9092	8.88	10.745
Rel. TEM (%)	1.4573	0.7275	0.975	2.6024	1.5496	1.8058	0.5991	0.6068

	LLI1 md	LLI1 bl	LLI2 md	LLI2 bl	LLC md	LLC bl	LLP1 md	LLP1 bl
Abs. TEM	0.06	0.1257	0.0587	0.1078	0.0844	0.204	0.0692	0.0979
VAV	5.1969	5.3954	5.7904	5.9053	6.9513	7.4933	7.0267	7.6064
Rel. TEM (%)	1.1541	2.3298	1.0137	1.8255	1.2142	2.7224	0.9848	1.2871

	LLP2 md	LLP2 bl	LLM1 md	LLM1 bl	LLM2 md	LLM2 bl	LLM3 md	LLM3 bl
Abs. TEM	0.1702	0.1518	0.235	0.1094	0.1045	0.2583	0.2644	0.2333
VAV	7.0253	8.145	11.1213	10.456	10.807	10.013	10.6806	10.1738
Rel. TEM (%)	2.4227	1.8637	2.1131	1.0463	0.967	2.5796	2.4755	2.2931

	LRI1 md	LRI1 bl	LRI2 md	LRI2 bl	LRC md	LRC bl	LRP1 md	LRP1 bl
Abs. TEM	0.117	0.0346	0.0808	0.1316	0.0595	0.2045	0.09	0.1348
VAV	5.1925	5.4563	5.8754	5.8638	6.5407	7.2132	7.045	7.5944
Rel. TEM (%)	2.2532	0.6341	1.3752	2.2443	0.9097	2.8351	1.2775	1.775

	LRP2 md	LRP2 bl	LRM1 md	LRM1 bl	LRM2 md	LRM2 bl	LRM3 md	LRM3 bl
Abs. TEM	0.1662	0.0841	0.0804	0.1541	0.0735	0.0247	0.177	0.1003
VAV	6.8136	8.0875	10.9313	10.5025	10.4042	9.8425	11.1542	10.3425
Rel. TEM (%)	2.4436	1.0399	0.7355	1.4673	0.7064	0.251	1.5868	0.9698

	ULM1 tr	ULM1 ta	ULM2 tr	ULM2 ta	ULM3 tr	ULM3 ta	URM1 tr	URM1 ta
Abs. TEM	0.0235	0.1001	0.0691	0.7394	0.0071	0.2864	0.074	0.1921
VAV	10.7944	6.8531	9.919	5.0756	10.025	2.7425	10.5324	6.8581
Rel. TEM (%)	0.2177	1.4607	0.6966	14.5677	0.0708	10.443	0.7026	2.801

	URM2 tr	URM2 ta	URM3 tr	URM3 ta				
Abs. TEM	0.089	0.9436	n/a	n/a				
VAV	10.2206	4.5764	n/a	n/a				
Rel. TEM (%)	0.8708	20.6188	n/a	n/a				