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Dental Anthropology Shines at AAPA Meetings

Dental Anthropology had a strong presence at the AAPA meetings in Milwaukee this April. Joel Irish and Greg Nelson organized and chaired an afternoon-long symposium on "state of the science," commemorating the Dental Anthropology Association's 20th anniversary AAPA meeting. A well-attended Dental Anthropology business meeting followed that evening.

Fourteen papers were presented during the symposium, spanning the topics of dental genetics, histology, microwear, growth and development, pathology, and morphometrics, across a wide range of extinct and extant human and non-human primate taxa. As the description of the symposium promised, these papers emphasized insights that the study of teeth provides into issues of fundamental anthropological importance. Such issues included the relationship of Neandertals to modern humans (Shara Bailey), inferring the diets of fossil primates and hominids through microwear or dental morphology (Mark Teaford, Peter Ungar and Sarah Taylor, Kalpana Agrawal and Peter Lucas), the correlation of dental development with life history variables (Gary Schwartz), and changes in dental and overall health associated with shifts in diet (Simon Hillson) and subsistence strategies (Brian Hemphill).

Other papers in the symposium focused on conceptual or methodological advances in the field. These included the relationship between genotype and phenotype in dental morphology (Leslea Hlusko and Michael Mahaney), the degree of inter-population variability in modern human dental development (Helen Liversidge), identification of the neonatal line using laser ablation techniques (Louise Humphrey, Christopher Dean and Teresa Jeffries), the use of perikymata to estimate the duration of linear enamel hypoplasias (Debbie Guatelli-Steinberg), the value of cervical crown measurements (Charles Fitzgerald and Simon Hillson), and finding the "hidden evidence" through virtual dentitions (Roberto Macchiarelli and Luca Bondioli). John Lukacs and Edward Harris, both past presidents of the DAA and discussants at the symposium, concluded the symposium with their perspectives on how the field of dental anthropology has changed over the last 20 years. They highlighted important advances that have followed from the incorporation of more sophisticated technology and analytic techniques.

With such a successful symposium, there was a festive mood at the Dental Anthropology Association Business meeting later that evening (and there is little doubt that the cash-bar arranged by Heather Edgar, Secretary-Treasure of the Association, contributed to the high spirits). Sally Graver, OSU Ph.D. student, introduced the new DAA Web site, designed by Alma Adler (Ph.D., Arizona State University). Sally urged everyone in the association to visit the site (http://monkey.sbs.ohio-state.edu/DAA/index.htm), which has DAA announcements and useful links, including links to Phil Walker and Ed Haagen's 3-D virtual images of the dentition. If you haven't checked these out, you should—they are wonderful to use in teaching because the images can be rotated into various perspectives.

Also at the business meeting, Edward Harris, Editor of *Dental Anthropology*, reported on the state of the journal. While articles published in the journal undergo peer review, Edward reminded us that other notices, news, and research updates are reviewed directly by the Editor. He encouraged us to submit to the journal any such items of interest to the Association. We plan to make the journal available on-line in the near future. Heather Edgar reported that the Association currently has approximately 200 members. The Dahlberg Prize was awarded to Robin Feeney. Sally Graver received the runner-up prize for her paper (see details, page 32). I want to thank the Dahlberg Prize judges once again for volunteering their time.

I hope that we can make next year just as exciting for the Dental Anthropology Association, which celebrates its 20th year as an AAPA-recognized organization in 2006. The Executive Committee is currently discussing ways to commemorate this important anniversary. In closing, I want to thank all who helped to make this year's meeting such a success for the Dental Anthropology Association and urge all of our members to become more involved in the Association by visiting the Web site and submitting manuscripts or other pieces of writing to the journal. Looking forward to next year in Alaska!

Debbie Guatelli-Steinberg
DAA President

Debbie Guatelli-Steinberg, DAA President, and Simon Hillson, President-Elect, enjoying a moment after the DAA business meeting.

An investigation of ultrasound methods for the assessment of sex and age from intact human teeth

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ABSTRACT Determining sex and age in human remains is necessary to achieve positive identification of individuals in forensic settings, and to provide data required for demographic analyses in archaeological samples. Due to their denser mineralization, teeth may be better preserved than other skeletal elements, which are often fragmentary and poorly preserved. This work is the first to investigate the use of ultrasound methods to accurately, objectively, and non-destructively assess sex and estimate age of human skeletal remains from intact teeth. An ultrasound imaging system using pulse-echo technique and nominal frequency (3.5 MHz) longitudinal waves was developed for application on teeth. Mechanical and acoustic properties of teeth were examined to explore their relationship with the interaction of ultrasound wave propagation. Experiments were conducted to determine differences in wave propagation in teeth from individuals of different ages and sex, both permanent and deciduous. Consistent differences in integral acoustic response patterns in the different teeth were found. It is concluded that pulse-echo ultrasound is a viable non-destructive technique to yield integral acoustic characteristic properties of teeth, potentially useful for assessing sex and estimating age, and resolving minimum numbers of individuals from commingled and scattered remains. Information developed from this study will be significant to future research insofar as it introduces a new potential method that is non-destructive, fast, and easy to administer *in situ*. *Dental Anthropology* 2005;18:2-11.

Determining sex and age in human remains is necessary to achieve positive identification of individuals in forensic settings and to provide data required for demographic analyses in archaeological samples. Due to their denser mineralization, teeth are generally better preserved than other skeletal elements, which can be fragmentary or poorly preserved. As a result, biological and forensic anthropologists are continually seeking accurate, objective, and non-destructive methods for assessing sex from dental remains.

External tooth dimensions have been used to determine sex in contemporary (Garn *et al*., 1977; Margetts and Brown, 1978; Potter *et al*., 1981; Garcia-Godoy *et al*., 1985; Kieser *et al*., 1985a,b; De Vito and Saunders, 1990) and archaeological (Lunt, 1969; Ditch and Rose, 1972; Scuilli *et al*., 1977; Owsley and Webb, 1983; Stermer Beyer-Olsen and Alexanderson, 1995; Teschler-Nicola and Prossinger, 1998) samples using population-specific discriminant function formulae. However, these functions are typically more descriptive, reflecting sex differentiation of the population, than

Robin Feeney (*left*) receiving Dahlberg Award from DAA President Debbie Guatelli-Steinberg.

Editor's note: Ms. Feeney's paper was awarded "First Prize" for 2005 in the Albert A. Dahlberg student research competition sponsored by the Dental Anthropology Association.

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predictive. Furthermore, interproximal attrition precludes obtaining proper measurements (Teschler-Nicola and Prossinger, 1998). Moreover, the degree of human sexual dimorphism in crown size is not pronounced and actual size differences in individual teeth between sexes are small (Hillson, 1996), relative to observer error.

Thickness of enamel and dentin from sections (Moore, 1998) and radiographs (Stroud *et al*., 1994; Harris *et al*., 2001; Zilberman and Smith, 2001) of teeth also have been used to investigate sexual dimorphism. Despite the larger size of male teeth, both relatively and absolutely, enamel thickness between the sexes does not differ significantly (Stroud *et al*., 1994; Moore, 1998; Harris *et al*., 2001; Zilberman and Smith, 2001). The results of these studies all found males to possess relatively more dentin and pulp than females. However, measurements taken from radiographs require correction for magnification (Grine *et al*., 2001). Alternatively, sectioning teeth is destructive.

Additionally, despite the fact that the deciduous dentition demonstrates significant sexual dimorphism (Moss and Moss-Salentijn, 1977; Black, 1978; Margetts and Brown, 1978; De Vito and Saunders, 1990; Harris, 1994) and that no reliable means of determining sex from juvenile skeletal remains exists, researchers typically have limited their studies to the permanent dentition.

In estimating dental age, it is established that the calcification stages of teeth are a superior indicator of chronological age than are the eruption status of teeth or even the ossification of the skeleton (Gleiser and Hunt, 1955; Lewis and Garn, 1960). Furthermore, there is a higher correlation between dental age and chronological age than there is between dental age and skeletal age (Demirjian, 1978). In addition, dental mineralization appears to be well buffered, being comparatively unaffected by nutritional (Garn *et al*., 1965a) and endocrine status (Garn *et al*., 1965b) that impact on the tempo of an individual's bony maturation.

Various other methods have been employed to estimate age from the dentition. Several histological methods of age estimation for adult remains exist that examine cementum annulation layers (Stott *et al*., 1982; Wittwer-Backofen *et al*., 2004) and secondary dentin deposits (Gustafson, 1950), but these are destructive of the tooth sample. Furthermore, morphological methods, including dental attrition (Brothwell, 1989) and periodontal regression and root translucency (Lamendin *et al*., 1992; Prince and Ubelaker, 2002), carry with them an element of subjectivity.

After the completion of tooth development, it is increasingly difficult to assess age accurately (Xiaohu *et al*., 1992). Studies by Philippas (1961) and Philippas and Applebaum (1966), on a large sample of modern permanent teeth from both sexes, found that with advancing age, irregular secondary dentin progressively fills the pulp chamber of the entire crown and root inward toward the pulp, in a natural process that occurs faster in the early years and more slowly later on, regardless of occlusal wear (attrition and abrasion). Changes in the structure of teeth with age, by measuring the increase in mineral content, seem to possess potential as a non-destructive method of estimating age from teeth.

The present pilot study is a first step in investigating the principles, limitations, and possibilities of using a pulse-echo ultrasound method to non-destructively, accurately, and objectively assess sex and estimate age of human skeletal remains from intact teeth. The study of mechanical and acoustic properties of enamel and dentin has been restricted to diagnostic ultrasound in the field of endodontics. The present work examines the mechanical and acoustic properties of teeth and explores their relationship with the interaction of ultrasound wave propagation. Experiments were performed to determine differences in wave propagation in teeth from different ages and sex, in both permanent and deciduous teeth, with other experimental factors. A description of the design and implementation of the dental ultrasound system developed in this research is presented, along with information for future development and improvement of the system and methodology.

PULSE-ECHO TECHNIQUE

Ultrasound are high frequency sound waves above the range of audible frequencies; above 20 kHz (Hussey, 1975). The analysis of sound wave disturbance along its propagation path forms the basis of ultrasound testing. Ultrasound wave motion creates disturbances in motion carrying energy, giving rise to wave properties, including the reflection a wave front, characteristic impedance[1], attenuation, and absorption, whose behavior produce acoustic phenomena (Wells, 1977). As a wave propagates from one medium to another, some of the wave energy is reflected back from the interface while the rest are transmitted through the second medium. If the ultrasound wave travels through more than two media, reflections will also occur at subsequent interfaces. The phenomenon of wave propagation in dental hard tissues is a complex interplay between the parameters of the sound wave and the characteristics of the medium. Ultrastructural differences in enamel and dentin give rise to differences in mechanical properties (hardness and elastic modulus[2]) of these

[1]Acoustic impedance: the opposition to the flow of sound through a surface in unit area when a wave meets the interface between two media (Wells, 1977).

[2]Elastic Modulus: or Young's modulus is the resistance of a material to stress: the greater the resistance, the greater the stiffness or modulus of elasticity (Wells, 1977).

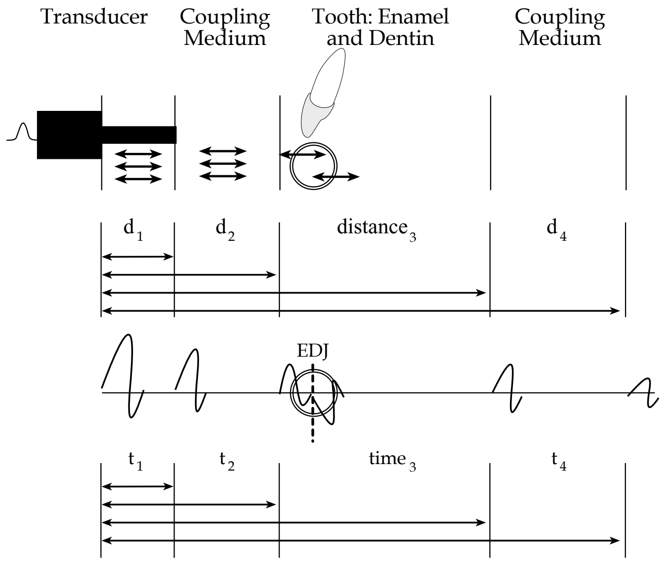

Fig. 1. Schematic illustration of the ultrasound pulse-echo technique. The circled regions indicate phase inversion. Orientation of the tooth relative to the transducer sensor beam is important because ultrasound waves will especially deviate when meeting a curved surface. Accordingly, specimens were placed in the test chamber with the most flat crown surface facing the sensor tip. Because only single-rooted teeth were studied, this commonl was the labial or buccal surface of the tooth.

tissues and result in marked difference in their sound characteristics (acoustic velocity and impedance). As a result of these differences, when ultrasound propagates from the surface of the tooth enamel into dentin, there are marked reflections at the enamel-dentin interface. Figure 1 diagrams the ultrasound pulse-echo technique, showing echoes corresponding to layers along the ultrasound beam path. Pulse 1 corresponds to the transducer surface, pulse 2 to the front surface of the coupling medium, pulse 3 to the tooth surface, and pulse 4 to the back surface of the coupling medium. Note that the second, third, and fourth echo travel the distance twice. As shown in Figure 1, with pulse-echo ultrasound imaging different surfaces that lie one behind the other can be separated. For that reason, pulse-echo information is valuable for measuring thickness of materials, such as enamel and dentin.

Pulse-echo patterns can also be used to analyze material properties of a tooth that are related to its acoustic characteristic impedance (Wells, 1977). If an ultrasound wave passes from a medium of higher impedance (*e.g.*, enamel) to one with lower impedance (*e.g.*, dentin), phase inversion (where the phase of a reflected wave is reversed) occurs at the EDJ. The effect of phase inversion is illustrated in Figure 1 as an inverted echo at the EDJ, occurring after the echo that corresponds to the enamel surface.

TABLE 1. Summary of the physical properties of acoustic media used in the experiments

Medium	Sound speed (m/s^{-1})	Density (kg/m^3)	Characteristic impedence (x10^6 kg s^{-1}m^{-2})
Water	1495	1000	1.5
Honey	2000	1500	3.0
Glycerol	1923	1173	2.3
Enamel	6000	2850	17.0
Dentin	4000	2150	8.6
Steel Transducer	5920	7850	4.6

MATERIALS AND METHODS

Tooth sample

A sample (n = 18) of clinically extracted permanent and deciduous incisor, canine, and premolar teeth from individuals of European and continental and sub-continental Indian descent was collected. The sample was chosen according to specific criteria: only those teeth that presented no or insignificant pathology (non-invasive carious lesions) and little wear were used. To avoid potentially complicated acoustic response signals, only single rooted teeth were used. Actual sex and age of the individuals were known.

Ultrasound system

Components of the ultrasound system developed in this research are presented in Figures 2 and 3. The data acquisition system consists of a single nominal frequency (3.5 MHz) longitudinal wave transducer, steel testing cell, a pulser/receiver cable, and an amplifier (Panametrics 200 MHz computer controlled pulser/receiver, model 5900PR). The data processing system consists of an oscilloscope with a disk data storage medium (LECROY 500 MHz oscilloscope, model 9350AM), a mainframe computer, and data processing software (MATLAB version 12.0).

The transducer (Fig. 3) is a custom-made product by Phoenix Inspection Ltd. (product number 976307). Electrical pulses applied by the amplifier and passing through the pulser/receiver cable attached to the transducer will transform into sonic energy in the form of an ultrasound wave that will propagate into the target media. The ultrasound cell (Fig. 3) was designed with sensor openings for the transducer to screw into. In this system, the transducer operates in a closed cell, rather than acting as a probe. In the center of the cell is the testing chamber, in which the tooth specimen is suspended during testing. The test chamber and transducer sensor tip were specially designed to accommodate the small size of human teeth in order to

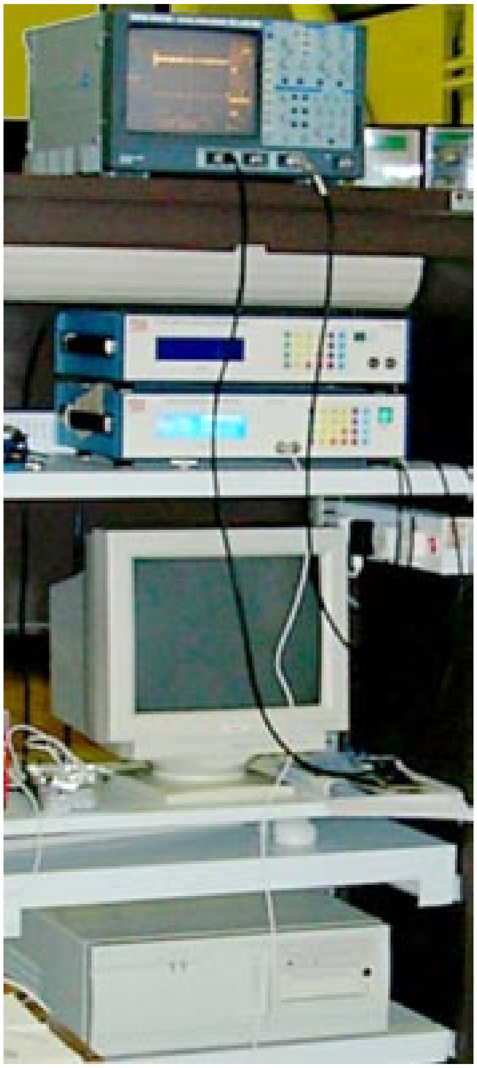

Fig. 2. Photograph of the oscilloscope, amplifier, pulser/receiver cable, and mainframe computer.

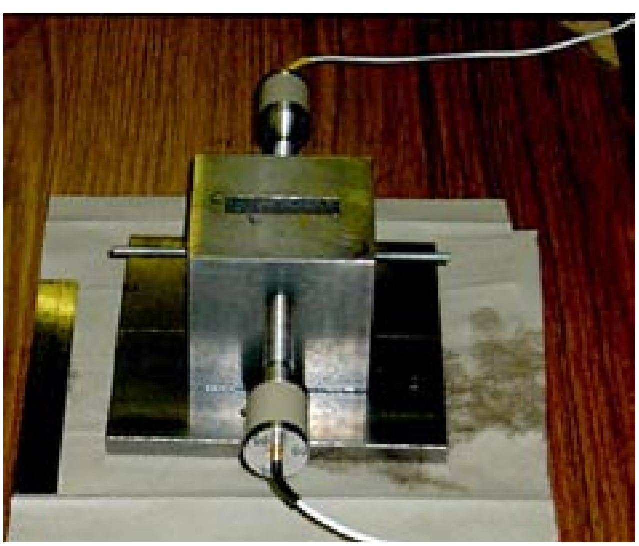

Fig. 3. Photograph of the ultrasound testing cell and transducer.

provide a better quality signal.

Experimental investigations

In order to achieve a superior acoustic response in teeth, additional experiments were conducted using different coupling media and specimens with different degrees of saturation. After these preliminary investigations were completed, a series of ultrasound tests were conducted on the tooth sample to obtain information on teeth from different ages and sex, in both the permanent and deciduous dentitions. Tests were also performed on different teeth from the same individual to explore the ultrasonic response to natural variation in teeth. In order for the results for each type of test to be comparable, the tooth specimens were matched for similar traits, such as sex, age, tooth class (incisor; canine; premolar), tooth type (first, second, third; upper, lower), and permanent versus deciduous throughout the experiments. Systematic tests disclosed no significant inter- and intra-observer error and disclosed significant reproducibility of the system.

RESULTS AND DISCUSSION

Dental ultrasound

It is difficult to find a suitable material to couple enamel. In theory, mercury (Reich *et al*., 1967) would be a good couplant to match the high characteristic impedance of enamel because of its fluidity and high density. However, its toxicity renders it unsafe for use and its high surface tension may lead to incomplete saturation in the presence of air-filled voids in the tooth. A coupling medium of relatively high density and high velocity was required to transfer energy from the transducer to the tooth. Typically, water is used as a couplant for teeth (Lees, 1968; Ng *et al*., 1989; Yang, 1991; Ng, 1993). However, the characteristic impedance of water is nowhere near that of enamel or dentin (Table 1), meaning that the coupling of ultrasound in dental tissues is very inefficient. This contrasts to situations involving soft tissues, where the characteristic impedance is similar to water and so energy losses are small. Preliminary experiments using distilled water resulted in a very weak ultrasonic response from the tooth, confirming significant acoustic energy loss.

Pure honey is a high velocity and dense fluid. In theory, because its acoustic impedance is closer to enamel than water (Table 1), it should couple better with the tooth, though it is viscous and has poor wetting properties. Preliminary experiments found pure honey to couple very well with teeth. As far as could be determined, no other investigator has used honey as a coupling medium for teeth. Glycerol, a less viscous medium than honey (Table 1), was also examined and was found to have coupling characteristics comparable to honey. Because honey is readily available and inexpensive, it was chosen as the coupling medium.

Saturation of the teeth was deemed necessary to eliminate air-filled voids resulting from the decay of tissues after extraction. Exclusion of air from the path of the ultrasound beam is important because air blocks the transmission of ultrasound. The effects of hydration on the acoustic properties of mineralized tissues have been previously reported (Smirnow and Wolfe, 1967; Barber *et al.*, 1969). The effects on the acoustic properties of teeth saturated for over 24 hours are not known. In this research, teeth were saturated in distilled water for a period of one hour and for several months. Notable differences were found. Teeth saturated for one hour demonstrated improved reflections compared to teeth saturated for several months. To a certain extent, the reflection qualities of a material depend on its material properties: a tooth with good structural integrity will reflect with more scatter than one of poorer structural integrity. Therefore, with longer periods of saturation, the internal structures of the teeth are likely to become less distinguishable ultrasonically due to decay. This finding is of significance, as it will assist in the development of procedural methods for future dental ultrasound testing.

Dental tissue thickness determination

In pulse-echo ultrasound, it is possible to calculate the distance (*i.e.*, linear measurements of tissue thickness) of enamel and dentin using the echoes corresponding to the enamel surface and the enamel-dentin interface. infact, on account of sensitivity problems and poor resolution of the image, it was not possible to detect these various interfaces. However, by working backwards: if the thickness of the enamel and dentin and the time taken for sound to travel through the honey coupling fluid, enamel, and dentin are known, time differences between echoes can be calculated (Appendix). This information is useful for approximating the enamel surface and the enamel-dentin junction (EDJ) echoes (Fig. 4). Ultrasound measurements were taken of the fluid filled chamber with no tooth (the reference measurement) and with a specimen present (Fig. 4). The specimen was removed from the test chamber and sectioned with a microtome in the same plane that the beam passed through in the tooth during ultrasound testing. Maximum thickness of enamel and dentin were measured from a photograph taken using a video microscope. Using these thickness measurements of enamel and dentin and the measured distance of the honey from the transducer sensor tip to the surface of the tooth in the test chamber, the times traveled by the ultrasound pulse in enamel, dentin, and in the honey coupling fluid were calculated (Appendix). With known time of flight of the ultrasonic pulse in these various media, the enamel surface and EDJ echoes in the time history plot (Fig. 4) could be approximated. At present, accuracy determinations are not possible

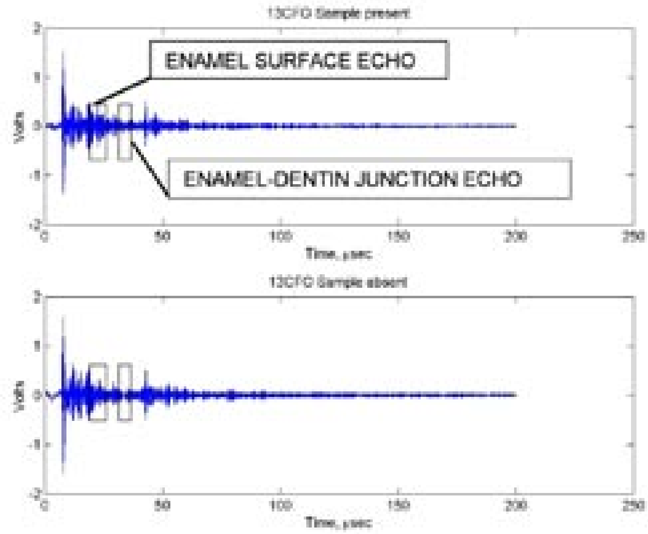

Fig. 4. Time history plot of the ultrasound response in a tooth (above) and in an empty chamber (below).

using the pulse-echo method developed in this research. Because the ultrasonic response is integral (*i.e.*, averaged values), it comes from different areas of the tooth, thus obscuring the reflections from the different tissue layers. A higher frequency transducer with better spatial resolution would focus ultrasound energy on a limited area of the tooth and provide better image quality, allowing more accurate determination of the various interfaces, and hence determinations of enamel and dentin thicknesses.

Material properties

In addition to calculating distances in materials useful for measuring tissue thickness, pulse-echo ultrasound is useful for detecting differences in properties in materials (Wells, 1977). On account of this, structural and compositional differences in a tooth may be detected by differences in wave propagation in enamel and dentin, which are the result of different acoustic behaviors related to the ultrastructure of these dental hard tissues.

Differences in wave propagation are measured in wave frequency, amplitude (sound intensity pressure), wavelength, wave speed, and energy transmission and intensity. The determination of these various measurements was not performed in this work. The sheer volume of data and specialized knowledge required to process the results make this an inappropriate method for use by anthropologists. Instead, a method that offers fast and easily interpretable results by examining patterns in wave propagation was undertaken. Although measured differences in wave propagation offer better scientific judgment of results, waveform plots demonstrating integral acoustic intensity at a given time and frequency window are used to detect patterns of wave propagation between different teeth (Figs. 5-8).

The waveform plots (Figs. 5-8) are based on a time-frequency dependency of reflected strength of the ultrasound field in a tooth. The reflection qualities in the ultrasound field depend, to a certain extent, on the material properties of the hard tissues of the tooth. Peaks and troughs in reflection packets, represented by clusters of dark spots and illuminations, characterize the strength of the reflections. When acoustic energy is lost due to absorption (*e.g.*, from air pockets in the tooth), very little of the signal has gone into the dental tissues, and this is represented by the dark spots in the images. In a time-frequency domain, improved reflections are represented by illuminated lines and patterns. The strength of the illuminations is characterized by a continuum of color, with lighter colors indicating higher intensity and darker colors indicating lower intensity. Beginning at approximately 140 microseconds, the tail ends of the plots are characterized by significant noise from reflections in the transducer waveguide and should not be interpreted.

Age differences

The progressive infilling of the root of a tooth with secondary dentin is correlated with age (Gustafson, 1950). Since the propagation of an ultrasound wave is affected by the material properties of a tooth, it is assumed that increased root dentin sclerosis in older individuals will provide different integral patterns of ultrasound wave propagation.

Teeth from individuals of varying ages were examined. Figure 5 represents the response pattern of lower central incisor teeth from a 12 and 45 year-old and premolar teeth from a 46 and 70 year-old. In general, a trend in increased reflection intensity can be observed in the teeth from younger to older individuals, revealed by increased illuminations and very few dark spots (Fig. 5). While better reflection qualities were observed in teeth from older individuals, likely due to advancing sclerosis, no obvious differences in wave propagation patterns were detected between similar teeth from individuals of different ages. New information, however, may become available with further data processing, by documenting the frequencies and times when a signal is present and performing statistical tests for pattern recognition.

Sex differences

Teeth from both sexes were examined and an apparent difference in the pattern of reflected energy intensity between the sexes was observed: a more uniform and band-like pattern was found to exist in female teeth, under 130 microseconds and in the 3-5 MHz frequency range, compared to males who exhibited a more distributed and irregular pattern in the whole of the frequency range (Fig. 6). Although discriminatory patterns of ultrasound wave propagation have been observed in teeth from different sexes it is difficult to determine exactly what these differences are. Most likely, these patterns are attributed to larger proportions of dentin in male teeth compared to females Stroud *et al.*, 1994; Moore, 1998; Harris *et al.*, 2001; Zilberman and Smith, 2001). Because dentin is less heavily mineralized than enamel, energy is more likely to attenuate in this tissue, resulting in the distributed and irregular pattern of reflected acoustic energy found in the male teeth. A larger sample is required to determine if these sex-specific patterns are statistically significant.

Permanent versus deciduous teeth

Original tests were undertaken to investigate ultrasound wave propagation in deciduous teeth. Figure 7 presents the ultrasonic response for a lower right

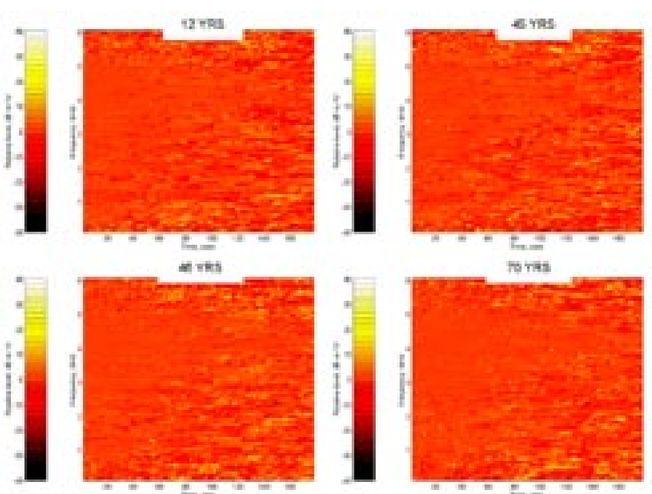

Fig. 5. Comparison of teeth from different aged individuals.

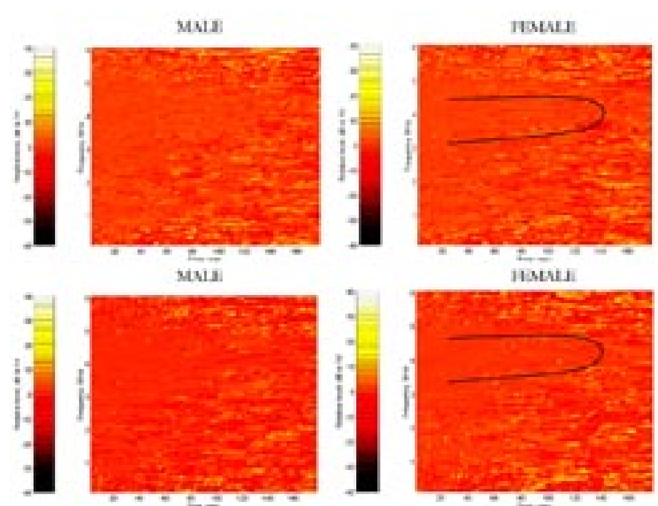

Fig. 6. Comparison of premolar teeth between different sexes.

deciduous canine and a lower left lateral deciduous incisor, compared with two permanent teeth of the same type, respectively. The distribution of acoustic energy arriving in microseconds and at frequencies in megahertz is markedly different between permanent and deciduous teeth. The deciduous teeth demonstrate a more uniform distribution of acoustic energy than permanent teeth, particularly below 90 microseconds and in the frequency range of 2-5.5 MHz (Fig. 7). This observed pattern in deciduous teeth, compared to their permanent counterparts, is attributed to differences in their dynamic properties. Apart from the paper by Mahoney and associates (2000) who determined that hardness and modulus of elasticity in deciduous enamel and dentin are within the range reported for permanent teeth, research on the mechanical and acoustic properties of deciduous teeth is lacking. Consequently, only speculations about the source of the wave propagation pattern observed in deciduous teeth (Fig. 7) can be made. For example, it is possible that because enamel in deciduous teeth is much thinner than in permanent teeth, the teeth are overall less hard, allowing for better coupling with the fluid medium, resulting in more energy being absorbed in the time-frequency window noted above.

The acoustic response pattern in deciduous teeth (Fig. 7) is notably similar to the patterns found in female teeth (Fig. 6), which display a uniform and clustered pattern of reflected energy in a high frequency range. It is possible that the ultrasonic response revealed in the deciduous specimens (Fig. 7) is attributed to the sex of these teeth: they are from females. Further investigation using a larger sample of deciduous teeth, however, is needed to confirm whether a unique pattern exists for deciduous teeth or whether the patterning is the result of other variables, such as sex.

Natural variation in teeth

Four deciduous canine teeth from the same individual were tested to investigate whether differences in natural variation in teeth could be detected ultrasonically (Fig. 8). Despite the difference in the reflected strength of the ultrasound field in the lower right specimen (due to an inconsistent saturation time) compared to the other three specimens (Fig. 8), the integral acoustic characteristic patterns were found to be remarkably similar. The most important finding in this experiment was that canine teeth from the same individual presented very similar patterns in the characteristic response of the ultrasound field. Further testing on a larger sample and improved data processing methods are required to determine if this finding is significant. If so, it may be possible, using the ultrasound method developed in this research, to discriminate between different individuals in commingled or scattered remains from their acoustic response patterns. Furthermore, it would be valuable

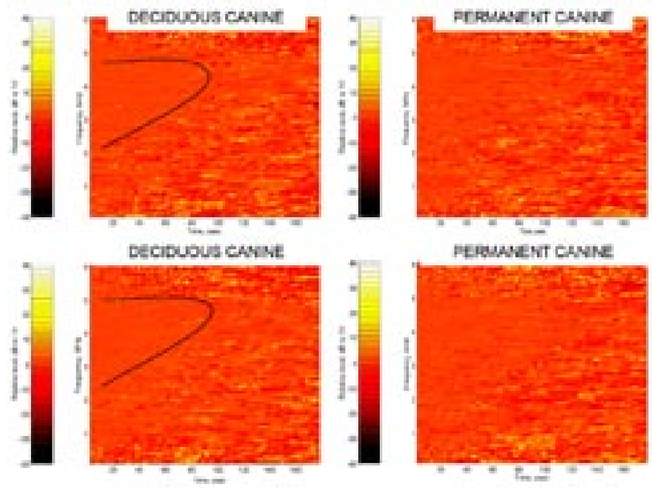

Fig. 7. Comparison between permanent and deciduous incisor and canine teeth.

to compare whether identical teeth from different individuals have different energy reflection patterns to test if the pattern in unique to individuals or to tooth class. This information may be of additional use in discriminating between individuals in mixed contexts.

Limitations and future directions

The sample (n = 18) is notably small and the discriminatory effectiveness of the results is questionable. Although sample size was modest, the study provided insight into the possible applications and intricacies of using pulse-echo ultrasound methods for anthropological study of teeth.

The values of acoustic impedance of the steel transducer, the honey couplant, and enamel and dentin are all very different (Table 1). This impedance mismatch results in great loss of ultrasound energy at the interface

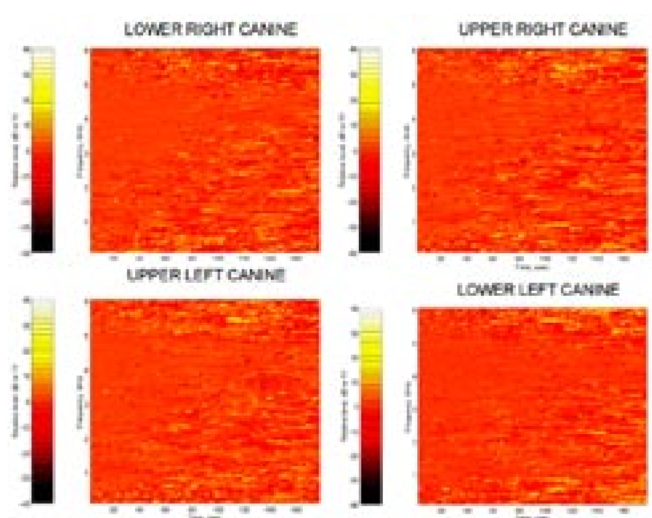

Fig. 8. Variation within canine teeth from the same individual.

between these media. In terms of acoustic impedance, a couplant more similar to enamel than honey would be preferred. Yet a material of such high acoustic impedance would most likely have to be a solid. The nearest match to enamel is aluminum. However, there are problems associated with using a solid coupling agent. A solid metal couplant would produce noise in the form of multiple reflections that would overshadow the echoes from the interfaces under study. Furthermore, it is difficult to physically adapt a solid to the curved surface of a tooth without taking invasive measures (*e.g.*, Lees and Barber, 1968; Barber *et al.*, 1969), which would negate the non-destructive nature of ultrasound testing and damage the valuable tooth. One possible solution would be to use a gel contained inside a thin, soft membrane glued to the transducer, as was tried by Spranger (1971) and Fukukita *et al.* (1985), which appeared to adapt well to oral tissue. Apart from the considerable mismatch between the steel transducer and enamel, honey is otherwise a good couplant because it is biocompatible, readily available, and inexpensive.

The resolution of the ultrasound system is mainly dependent on the transducer characteristics. In the works by Yang (1991) and Ng (1993), the echo from the enamel-dentin interface was only observed on some portions of the tooth surface. Often, some areas of the tooth surface are rough or ridged and the enamel surfaces may not have been formed in parallel or in near parallel with the EDJ. These factors make the detection of the enamel-dentin interface difficult. To resolve this, a higher frequency transducer than 14.5 MHz and 18 MHz, used by Yang (1991) and Ng (1993), respectively, should be used. Resolution problems experienced in this research may be resolved with the use of a single focused high frequency transducer. A focused high frequency transducer would offer high resolution by achieving good lateral resolution, which would enable better imaging of the curved surfaces and accommodate variation in teeth.

Of additional importance is the execution of testing and data processing. In contrast to the mounting, sectioning, and microscopic procedures normally required to obtain information about sex and age from dental remains, the operation of the ultrasound system developed in this research is both quick and straightforward. Moreover, the compact size and relatively light weight of the ultrasound testing cell and oscilloscope with data storage medium renders this system ideal for administering tests *in situ*, rather than in a specialized laboratory. The methods for processing the data are, however, protracted. At present, specialized knowledge of software designed to process ultrasound data and to transform it into interpretable plots is essential, as is experience interpreting the results. However, the dental ultrasound system is in the pilot stage of development. With further work, more simplified software can be developed for straightforward use and simple interpretation for use by non-specialists.

Apparent differences in integral acoustic characteristic patterned responses were observed in different types of teeth in these experiments. Further processing of data, such as documenting the frequencies and times when a signal is present and performing statistical tests for pattern recognition to find significant patterns, may offer further information on which to base interpretations. Additionally, the development of a prediction model for wave propagation in teeth (*e.g.*, Ghorayeb *et al.*, 1998; Ghorayeb, 2001) may further facilitate interpretations. Nevertheless, although the results do not provide a statistical basis for definitive judgment, consistent differences have been observed in the patterns of the time of arrival of the ultrasound energy in microseconds and in frequencies at megahertz in teeth, particularly in teeth from different sexes, deciduous teeth, and in identical types of teeth from the same individual.

SUMMARY AND CONCLUSIONS

This paper describes original work conducted on the use of pulse-echo ultrasound as a means of non-destructively assessing sex and estimating age in skeletal remains from intact teeth. The most important findings presented are: (1) non-destructive ultrasound imaging of intact human teeth, (2) non-destructive means of measuring intact enamel and dentin tissue thickness, (3) detection of consistent acoustic integral response patterns for different types of teeth, and (4) development of the understanding of how dental anisotropic materials and natural variation affect ultrasound wave propagation. Investigation of these endeavors in this research has provided additional information valuable for the future development of instrumentation and methodology for non-destructive ultrasound imaging of teeth. The dental ultrasound system has a number of feasible applications, even in its present state of development, but the accuracy of the ultrasound system and the smallest change that it can detect need to be determined. Furthermore, the development of software to assess for statistically significant patterns is required to eliminate subjectivity.

Ultrasound could be applied to the study of teeth if a thorough understanding of wave propagation in teeth were available. The difficulties are caused by the physical situation of the teeth, compounded by high-resolution requirements. The principal problems experienced in this research were: (1) small physical size of teeth, (2) complex structure and gradients in mechanical properties of teeth, (3) irregular shape of the teeth characterized by complex surface morphology, and (4) difficulty transmitting sound waves through the tooth. Although the dental ultrasound system developed in this research is not accurate enough at present to be of practical use, the results that have been obtained are encouraging. There exists a great deal of room for improvement of the system and ultrasound remains a promising method to tackle the problem of non-destructive study of teeth. From the abbreviated discussion of ultrasonics in this work it appears likely that significant possibilities, such as determining sex and age of remains from teeth ultrasonically, lie in the development of the instruments capable of providing precise and quantitative measurements.

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APPENDIX

Calculating distances from ultrasound measurements:

1) Scale: 1 mm = 18 mm on video microscope photograph
2) Sound Speed (c) in m/s^{-1}:
   - Enamel: 6000
   - Dentin: 4000
   - Honey coupling fluid: 2000
3) Maximum thickness measurements:
   - Enamel: 17 mm on video microscope photograph = 17/18 x 1 mm = 0.94 mm
   - Dentin: 34 mm on video microscope photograph = 34/18 x 1 mm = 1.89 mm
   - Honey: 4 mm from transducer sensor tip to front surface of tooth in chamber
4) Time travelled (*t*): *t* = Dc, where D = distance; c = sound speed:
   - Enamel: 0.94 x 10^{-3} x 6000 = 5.64 µsec (x 2 for return pulse = 16 µsec)
   - Dentin: 1.89 x 10^{-3} x 4000 = 7.56 µsec (x 2 for return pulse = 15.12 µsec)
   - Honey coupling fluid: 4 x 10^{-3} x 2000 = 8 µsec (x 2 for return pulse = 16 µsec)

Dental Health Decline in the Chesapeake Bay, Virginia: The Role of European Contact and Multiple Stressors

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ABSTRACT: This study tests the hypothesis that the arrival of Europeans in Jamestown, Virginia, had a negative impact on the dental health of native populations in the Chesapeake Bay. Data were collected on three variables—dental caries, periapical lesions, and antemortem tooth loss—in a sample of 644 individuals from four prehistoric (n = 500) and two contact era ossuaries (n = 144) from the Potomac Creek site in Virginia (44ST2). Statistical analysis reveals a trend of declining dental health for the post-contact sample (chi-square; $P<0.05$). The temporally latest ossuary had the highest prevalence of all indicators. There is also a trend toward poor dental health for females relative to males. In particular, females have a higher prevalence of carious lesions and antemortem tooth loss than males. Sex differences in dental health probably correspond to sex-based differences in food production and preparation in this setting, since females likely ate more cariogenic foods. Multiple factors likely explain the general pattern of decline in dental health, including: (1) a change in diet involving greater consumption of carbohydrates, (2) increased exposure to infectious pathogens, (3) warfare and other forms of conflict, (4) strain on resources, and (5) increased population density. *Dental Anthropology* 2005;18:12-21.

The biological impact of European exploration and expansion had varied consequences on the health of native populations in the New World (Baker, 1994; Baker and Kealhofer, 1996; Larsen and Milner, 1994; Larsen *et al.*, 2001; Pfeiffer and Fairgrieve, 1994; Ubelaker, 1993; Verano and Ubelaker, 1992). Health effects differed according to several factors, including the motivation of European explorers (*e.g.*, religious or economic), duration of contact, and native cultural and physical environments (Baker and Kealhofer, 1996; Larsen and Milner, 1994; Larsen, 2001; Ubelaker and Curtin, 2001; Verano and Ubelaker, 1992). Previous historical and archaeological literature has emphasized the negative consequences of contact for both immigrant and native populations, concentrating on disease and epidemics (*e.g.*, Cook and Lovell, 1991; Crosby, 1986; Dobyns, 1983, 1993; Sale, 1990). More recent work has demonstrated that biocultural responses to contact were not uniform, and that native populations adapted differently to post-contact conditions (Baker and Kealhofer, 1996; Larsen, 1994; Larsen and Milner, 1994). Few bioarchaeological analyses have focused

Sally Graver (*left*) receiving Dahlberg Award from DAA President Debbie Guatelli-Steinberg.

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on issues of contact in the Chesapeake Bay region (but see Mecklenburg, 1969; Miller *et al.*, 1999), where long term contact commenced with the founding of Jamestown by British colonists in 1607 (Dent, 1995). In order to completely understand the contact experience in North America, it is important to document this cultural encounter.

The purpose of the present study is to test the hypothesis that contact with English settlers resulted in a decline in the dental health of native populations in the Chesapeake Bay. In order to test this hypothesis, the dental remains of a Patawomeke Indian population originating from four prehistoric and two contact era ossuaries at the Potomac Creek site in Virginia (44ST2) were examined (Fig. 1). The population under study is known historically to have had an intimate relationship with the Jamestown colonists and represents an excellent population sample on which to test this hypothesis. Data were collected for three dental health indicators: dental caries, periapical lesions, and antemortem tooth loss in order to assess whether a decline in dental health occurred in the Chesapeake Bay during the transition from the late prehistoric period to the contact era.

Dental health indicators

Dental caries is a pathological process resulting in destruction of tooth structure by acid-forming bacteria found in dental plaque (Hillson, 2000; National Library of Medicine, 2001; Schachtele, 1990). Populations with diets high in carbohydrates or other dietary sugars (such as maize) are predisposed to dental caries and poor oral health in general (Hillson, 2000; Hutchinson and Larsen, 2001). This positively correlated relationship is well documented in both bioarchaeological and medical literature (Larsen, 1983; Lukacs, 1992; Newbrun, 1982; Schachtele, 1990; Turner, 1979; Walker and Hewlett, 1990). Furthermore, caries rates have been relatively low throughout prehistory until the adoption of agriculture and, thus, the addition of cariogenic foods into the diet (Hillson, 2000; Larsen, 1995; Larsen *et al.*, 1991). Increases or decreases in caries rates can document dietary change in prehistory (Hillson, 2000; Larsen, 1997).

Caries is a slowly progressive, age-related disease. Therefore, age data are important for understanding caries frequencies. Caries rates are also typically higher in molars and premolars (Hillson, 2001). This disease results when the cariogenic component of the diet is increased and constant (Schachtele, 1990).

Anthropological literature commonly uses the term "abscess" to refer to periapical lesions in the alveolar bone; however, abscess formation is only one of several possible inflammatory responses (Alt *et al.*, 1998; Dias and Tayles, 1997; Hillson, 2000). The differential diagnosis of periapical lesions in prehistoric populations is a problematic; therefore, periapical granulomata, cysts, and abscesses collectively are classified here as *lesions*. Periapical inflammation of the alveolus results from soft tissue infection where bacteria spread and cause pulp chamber inflammation (pulpitis) (Hillson, 2000). This inflammation is usually painful and can be due to a number of factors, including excessive dental wear, carious lesions, periodontitis, dental impactions, tooth fracture, or pulp chamber exposure (Buikstra and Ubelaker, 1994; Dias and Tayles, 1997; Hillson, 2000; Larsen, 1997).

The alveolar process has very active bone remodeling at all ages (Hillson, 2000; Verna *et al.*, 1999). When a tooth is lost during life, the alveolus gradually resorbs the socket and remodels bone to create a smooth flat surface where the tooth had been before it was lost. In archaeological populations, periapical inflammation and abscesses generally result in the loss of teeth and eventual resorption of the alveolus (Hillson, 2000; Larsen, 1997). Other factors that may contribute to tooth loss during life include chipping or breakage, extraction, wear, periodontal disease, or trauma (Hillson, 2000).

Biocultural setting

A decline in the dental health of Native Americans has been documented elsewhere in North America after European contact (*e.g.*, Baker, 1994; Hill, 1996; Kelley *et al.*, 1987; Larsen *et al.*, 2001; Stodder and Martin, 1992; Walker and Johnson, 1992, 1994). While the motivations of the Spanish, French, and English in the New World varied, the effects of their colonization on native populations share some common outcomes. Throughout North America, exposure to European diseases reached epidemic proportions and drastically reduced native population size (Baker, 1994; Baker and Kealhofer, 1996; Brose *et al.*, 2001; Fitzhugh, 1985; Larsen, 2001; Larsen and Milner, 1994; Larsen *et al.*, 2001; Pfeiffer and Fairgrieve, 1994; Ubelaker, 1993; Ubelaker and Curtin, 2001; Verano and Ubelaker, 1992). Other studies, however, indicate that late prehistoric levels of dental pathology were already high due to the intensification of agriculture, and that contact with Europeans did not necessarily affect the dental health of natives (Cybulski, 1994; Hutchinson and Larsen, 2001; Miller, 1996; Pfieffer and Fairgrieve, 1994; Reinhard *et al.*, 1994; Stodder, 1996). For instance, Pfieffer and Fairgrieve (1994) found no significant difference in caries prevalence, abscesses, and linear enamel hypoplasias between prehistoric and post-contact Iroquois ossuaries. Although evidence suggested that episodic stress and disease prevalence increased from the late prehistoric to post-contact times, the authors were reluctant to conclude European contact was solely responsible for the trend in declining health over time.

European-introduced diseases may have devastated Chesapeake natives, although sources disagree about the scope of this phenomenon. European accounts from the 17th and 18th centuries offer conflicting accounts about the health of native populations in the Chesapeake, leading some historians to claim that no major epidemics occurred around the time of contact (*e.g.*, Potter, 1993; Rountree, 1990; Turner, 1985). Other scholars suggest it is impossible to ignore the impact of European diseases on native populations (Dent, 1995; Rountree, 1989; Ubelaker, 1993; Ubelaker and Curtin, 2001). Early Jamestown colonists Gabriel Archer and William Strachey claim that native groups were ravaged by disease, most likely smallpox (Archer, 1969; Strachey, 1953; Ubelaker and Curtin, 2001). Chesapeake natives were almost certainly subjected to repeated epidemics of smallpox, measles, whooping cough, typhoid, mumps, syphilis, influenza, plague, and scarlet fever, which greatly decreased population size in the 16th and 17th centuries (Ubelaker, 1993; Ubelaker and Curtin, 2001).

Europeans arrived in the Chesapeake at a time when population pressure, drought, declining health, and conflict were widespread (Potter, 1993; Rountree, 1989). Tree-ring data from Virginia and sediment cores from the Chesapeake indicate that two severe droughts, the first occurring prior to contact (AD 1587-1589) and the second just after the settlement of Jamestown (AD 1606-1612), would have been devastating to native subsistence practices (Cronin *et al*., 2000; Richardson *et al*., 2002; Rountree, 1989; Stahle *et al*., 1998). The second severe drought has been suggested as a possible contribution to the deaths of 70 of the 104 colonists during the first year of settlement at Jamestown and to high mortality during the next decade (Blanton, 2000; Richardson *et al*., 2002, Stahle *et al*., 1998). Natives were accustomed to minor droughts every three years (Rountree and Turner, 2002), but were not prepared to share resources with Europeans during a severe drought. With contact came new problems for native populations that would inevitably change their way of life.

Archaeological data indicate that an increase in native population growth and the development of chiefdoms brought prehistoric native groups into conflict. New alliances and trade with Europeans were also disruptive to native political systems, often pitting native groups against each other (Axtell, 1988; Dent, 1995; Potter, 1993). The arrival of the Jamestown colonists made competition for resources more acute. One strategy for survival was to cooperate with the new immigrants. The Patawomeke employed such a strategy by allying themselves with the British against their old rivals, the more powerful Powhatan (Potter, 1993).

Subsistence

The intensification of domesticated plants, specifically maize, negatively impacted the health of native groups in the Chesapeake Bay (Hoyme and Bass, 1962; Ubelaker, 1993). A maize-based diet is marginally sufficient in protein, vitamins, and minerals, depending on processing techniques and supplemental foods (Messer, 2000). Additionally, maize is low in the essential amino acids lysine and tryptophan as well as calcium and niacin (Ensminger *et al.*, 1995; Messer, 2000). Without adequate supplementation, a maize-based diet is deficient in iron, due to the presence of phytates that inhibit the absorption of iron by body tissues (Baynes and Bothwell, 1990). The negative effects of a diet high in maize can be clearly observed in a comparison of inland and coastal skeletal samples in the Chesapeake region. Chase (1988) found that coastal populations exhibited less evidence of anemia (porotic hyperostosis and cribra orbitalia) than the inland populations. She argued that this difference was due to the higher level of marine resources available to coastal populations, which can offset the problems associated with maize (Chase, 1988; Messer, 2000; Papathanasiou *et al*., 2000). Stable isotope data confirm this hypothesis.

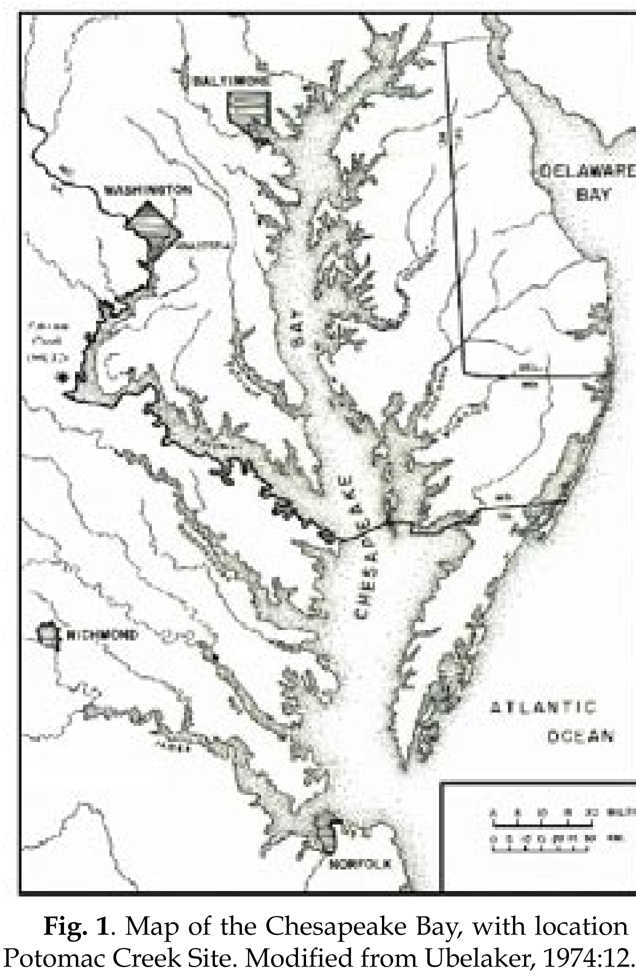

Fig. 1. Map of the Chesapeake Bay, with location of Potomac Creek Site. Modified from Ubelaker, 1974:12.

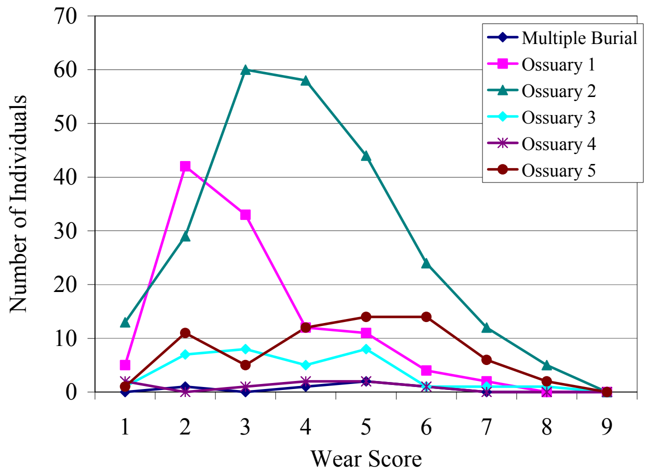

Fig. 2. Average wear score by ossuary. Wear scores are based on the eight-grade system developed by Smith (1984), with grade 1 being no wear.

An analysis of stable carbon and nitrogen isotopes from Late Woodland skeletal samples from Virginia demonstrate that maize comprised a significant proportion of diets from all regions (25-50% in the Coastal Plain), while only the coastal populations had significant marine resources incorporated in the diet (Trimble, 1996). Fourteen individuals sampled from the population under study were compared to other Coastal Plain, Piedmont, and Appalachian populations from the Late Woodland Period. Of the 15 sites sampled, Potomac Creek populations had the lowest mean δ^{13}C and δ^{15}N values, indicating that their diet consisted of the highest proportion of marine or freshwater resources (Trimble, 1996). Trimble (1996) argues that maize contributed about 20 to 50% of the Patawomeke diet, and that prehistoric C_4 plant usage at Potomac Creek was lower than the other 14 sites.

Studies have also shown a positive correlation between a maize-based diet and high caries rates in prehistoric populations (Cook, 1984; Larsen, 1995, 1997; Larsen *et al.*, 1991). The traditional method of preparation in the Chesapeake Bay included grinding and boiling maize into a soft gruel (Smith, 1986a). The preparation of maize into a sticky, starchy mush increases the likelihood that food particles will become caught in tooth grooves during mastication, which make teeth more prone to dental caries (Cook, 1984; Reeves, 2001). Moreover, maize-based diets show strong association with poor health, including high frequencies of antemortem tooth loss, iron-deficiency anemia, and periapical lesions (Baynes and Bothwell, 1990; Cook, 1984; Cohen and Armelagos, 1984; Larsen, 1995, 1997; Larsen *et al.*, 1991). A poor diet, such as one that emphasizes maize without sufficient supplementation of iron and protein, results in poor nutrition, which leads to a greater susceptibility to infection and disease (Ensminger *et al.*, 1995; Messer, 2000, Powell, 1988).

MATERIALS AND METHODS

The sample consists of a minimum number of 644 individuals from the Potomac Creek site (44ST2), which is located on the western shore of the Potomac River in Stafford County, Virginia (Fig. 1). The remains are curated at the National Museum of Natural History, Smithsonian Institution, Washington, D.C. Two of the burial contexts contain European trade items that indicate use of the site during post-contact times.

The sample (n = 644) consists of four pre-contact (<AD 1607; n = 500) and two post-contact (>AD 1607; n = 144) ossuaries. An ossuary involves a mortuary practice that is defined as the “collective, secondary deposit of skeletal material representing individuals initially stored elsewhere” (Ubelaker, 1974:8). Ossuaries should not be confused with mass burials, as the latter implies that individuals died around the time of their deposit. Because of their commingled nature, ossuaries present several unique problems to bioarchaeologists.

Demographic profile

Demographic information was difficult to determine in this sample due to the disarticulated, commingled, and highly fragmentary nature of the remains. Age and sex were based on dental development, dental wear, and sexually dimorphic cranial features (Table 1). Except for Ossuary 5, all samples are represented by a small percentage of juveniles and an abundance of

Table 1. Demographic distribution by ossuary

Temporal Period	Ossuary	Males		Females		Indeterminate		Juveniles		Total
		n	%	n	%	n	%	n	%	n
Post-Contact	Multiple Burial Pit	2	29	0	0	2	29	3	42	7
Post-Contact	Ossuary 1	20	15	10	7	102	74	5	4	137
Pre-Contact	Ossuary 2	69	21	56	17	176	54	22	8	323
Pre-Contact	Ossuary 3	7	15	8	17	28	61	3	7	46
Pre-Contact	Ossuary 4	0	0	0	0	18	86	3	14	21
Pre-Contact	Ossuary 5	30	27	29	26	13	12	38	35	110

Table 2. Prevalence of adult carious lesions per tooth class

Ossuary	UM n	UM %	UP n	UP %	UC n	UC %	UI n	UI %	LM n	LM %	LP n	LP %	LC n	LC %	LI n	LI %	Total n	Total %
MBP	4	33	0	0	5	100	2	40	2	33	4	50	0	0	1	7	18	30
1	78	43	26	18	12	16	23	21	111	55	41	26	19	22	7	8	317	31
2	207	43	92	28	30	19	28	16	213	53	77	24	19	12	14	7	680	31
3	16	27	11	18	3	10	1	5	18	38	1	33	2	12	0	0	52	19
4	4	30	1	13	1	50	0	0	3	25	1	14	1	50	0	0	11	23
5	68	33	38	23	14	15	11	9	88	49	34	20	6	6	4	3	263	23

adults of indeterminate sex. Data collected on juvenile permanent dentition were pooled with adults for dental caries only.

Since other bone elements could not be associated directly with crania or isolated teeth, an estimate of adult age is provided by an analysis of dental wear (Fig. 2). Studies have shown a strong correlation between age and dental wear in archaeological populations (Smith, 1984; Walker *et al*., 1991). Dental wear was scored following the eight stages proposed by Smith (1984) for all individuals and loose teeth by ossuary. Due to the high degree of postmortem tooth loss, an average wear score of all present teeth was calculated for complete sets of dentition; loose teeth were scored on an individual basis. These data are provided to identify possible confounding factors in the analysis of age-related dental pathological indicators: dental caries, antemortem tooth loss, and periapical lesions (Hillson, 2000).

Dental health indicators

Carious lesions were recorded for each tooth by number of carious lesions per tooth and location of lesions. Periapical lesions were identified by the presence of a drainage channel leading from the apex of the tooth root through the alveolar bone, resulting in a granuloma, cyst, or abscess (Buikstra and Ubelaker, 1994; Dias and Tayles, 1997). Antemortem tooth loss could only be determined from direct observation of alveolar bone of the maxilla and mandible. Tooth loss was documented when the associated alveolar bone was partially or totally resorbed.

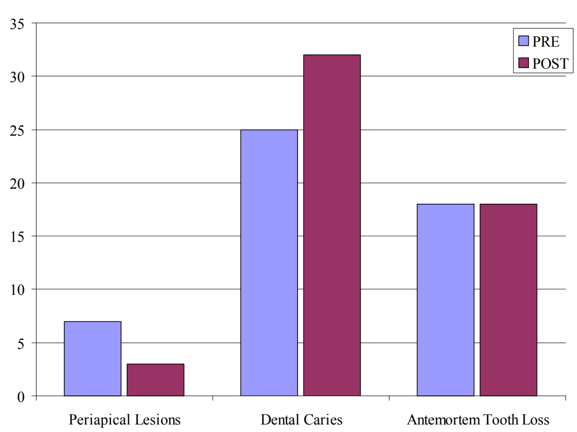

Fig. 3. Prevalence of dental health indicators by temporal period.

Statistical analysis

Chi-square statistics were applied to the data set in order to test for significant differences between samples. For each dental health indicator, statistical tests were conducted among ossuaries, between combined pre- and post-contact samples, and within each ossuary (by sex). Due to the commingled and fragmentary nature of the remains, it was impossible to separate the samples by age categories other than adult and juvenile.

RESULTS

Dental caries

Dental caries rates are high among adults (Table 2) from all burial samples. A comparison of combined burial samples (including adults and juvenile permanent dentition) demonstrates significantly greater caries rates in the post-contact sample than in the pre-contact ossuaries (Fig. 3). Two ossuaries show significant variation between the sexes: Ossuary 2 females have higher caries rates for molars than males and Ossuary 5 females have greater overall caries rates than males.

Periapical lesions

Although periapical lesions were relatively few among all samples, lesion prevalence is significantly greater in the pre-contact sample (Fig. 3, Table 3). Sex differences within samples indicate that males have a higher lesion prevalence than females.

Table 3. Periapical lesion and antemortem tooth loss prevalence for adults by ossuary and combined samples

	Periapical Lesions		Antemortem Tooth Loss	
Ossuary	n	%	n	%
MBP	8	13	21	35
1	34	3	256	19
2	251	7	785	19
3	5	4	49	10
4	103	7	10	8
5	42	3	371	24
Post-contact	42	3	277	19
Pre-contact	409	7	1215	19

Antemortem tooth loss

Antemortem tooth loss is common for adults in all samples (Table 3). Significant differences do not exist between pre-contact and post-contact samples (Fig. 3); however, post-contact males have greater posterior tooth loss than pre-contact males. Comparisons by sex among ossuaries indicate that females consistently have higher levels of antemortem tooth loss than males.

DISCUSSION

The results of this research are summarized as follows. Except for Ossuary 5, all samples are represented by a small percentage of juveniles and an abundance of adults of indeterminate sex. Juvenile data were only collected for dental caries and were pooled with adults for the permanent dentition only. The post-contact multiple burial pit consistently had the highest prevalence of dental pathological indicators for each category. However, this sample is the smallest (n = 7), so less confidence should be placed in these results. Ossuary 1, the other post-contact sample, had lower than expected prevalence data for dental health indicators. The lower lesion prevalence for Ossuary 1 may be due to the younger age composition of the adults in this sample. The combined post-contact samples had significantly greater caries prevalence than the pre-contact sample. The pre-contact sample had more periapical lesions than the post-contact sample, and there were no differences between pre- and post-contact samples for antemortem tooth loss. There was a trend towards higher caries rates and antemortem tooth loss for females, and higher periapical lesions prevalence for males.

An appraisal of the demographic distribution of the ossuaries from the Potomac Creek site reveals considerable variation. The small sample size and lack of available sex data precluded some comparisons with the multiple burial pit and Ossuary 4. Tooth wear estimates for each burial sample reveal that Ossuary 1 and Ossuary 2 have more young adults than older adults, while the converse is true for the sample from Ossuary 5. Therefore, age may be a confounding factor in prevalence data for Ossuaries 1, 2, and 5.

Dental caries

At the Potomac Creek site, caries rates increased after contact with the Jamestown colonists. An increase in caries rates after European contact has been documented elsewhere in the New World after contact. For example, Larsen and colleagues (1991) suggest that the post-contact increase in caries rates for native populations in La Florida was due to increased production and consumption of maize, concomitant with the change to a mission lifestyle. The Patawomeke were probably producing more maize as well, since they supplied maize and other foods to the colonists on several occasions (Potter, 1993).

The trend of higher caries rates for females is not uncommon in populations dependent upon maize. Studies show higher caries rates for females in agricultural populations in the New World, probably due to sex-based differences in food preparation and consumption (Hillson, 2000; Larsen *et al*., 1991).

Periapical lesions

Contrary to the expected results, periapical lesion prevalence decreases after contact. It is often difficult to identify the cause of periapical lesions, but its etiology is commonly linked to dental caries and severe dental wear (Hillson, 2000). A number of possible causes for the higher rates of periapical lesions among the pre-contact population can be proposed: 1) a change in diet associated with contact, 2) poorer oral hygiene, or 3) more abrasive foods in the diet (causing more dental wear).

Males display more periapical lesions in half of the samples from the Potomac Creek site. These results are unexpected due to the higher caries rates in females and ethnohistoric evidence for females consuming more cariogenic foods. A possible explanation for this difference is a higher rate of antemortem tooth loss among females; if females are losing more teeth, or losing them earlier than males, it is likely that the prevalence of periapical lesions would be lower among females.

Antemortem tooth loss

Antemortem tooth loss appears not to have changed over time. However, a comparison of male posterior teeth demonstrates that antemortem tooth loss did increase after contact. These results approximate the expected outcome for this analysis. Furthermore, in three of the samples (Ossuaries 2, 3, and 5), females had significantly higher rates of tooth loss than males, possibly elucidating the unexpectedly higher periapical lesion prevalence among males. A greater rate of antemortem tooth loss among females is consistent with the sex-based differences in diet.

CONCLUSIONS

The dental pathological indicators used in this study provide information about diet, nutrition, and physiological stress among the Patawomeke and insight into the dental health of this population. This research suggests that the arrival of Europeans in the Chesapeake Bay had a profound impact on the dental health of native populations. It was expected that the Patawomeke populations would have been acutely affected since they dealt first-hand with Europeans, as both allies and, at times, enemies. The Patawomeke often provided the major source of subsistence to the Europeans, trading bushels of corn for copper, beads, and other non-food items (Potter, 1993; Smith, 1986b). The trading of valuable food resources would have put a strain on native populations. English colonists also resided in close proximity to the Patawomeke on several occasions (Potter, 1989), especially in times of war with the Powhatan. The close quarters may have facilitated the spread of diseases to which natives were not immune, and would have put a strain on their subsistence resources and daily activities.

This study reveals significant differences in all three dental pathological indicators between sexes, a phenomenon that has been observed in other agricultural populations (*e.g*. Cohen and Armelagos, 1984). A post-contact decline in dental health and dietary quality has also been documented in many regions of North America, including the Northeast (Baker, 1994), the South (Hill, 1996), the Southwest (Stodder and Martin, 1992), and the West (Walker and Johnson, 1992). Other studies, however, indicate that late prehistoric levels of dental pathology were already high due to the intensification of agriculture, and that contact with Europeans did not affect the dental health of natives (Miller, 1996; Pfieffer and Fairgrieve, 1994; Reinhard *et al*., 1994). The results of this study support the hypothesis that Native American dental health declined after contact with Europeans in the Chesapeake Bay. This research suggests that the dental health of the Patawomeke of the Potomac Creek site declined following founding of Jamestown due to multiple factors, including: (1) a change in diet, (2) exposure to new diseases, (3) warfare or conflict, (4) strain of resources, and (5) increased population density.

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DAA Web Site Updated and Expanded

Thanks to the efforts of Sally Graver (Ph.D. student, Ohio State University), the Dental Anthropology Association Web site has a new home. The new Web site address is:

http://monkey.sbs.ohio-state.edu/DAA/index.htm

This is located on the Ohio State University Department of Anthropology's server. Notice that this address is different from that published in the last issue—and should be more robust.

Alma Adler designed the Web site, which currently has links to the membership form, Dahlberg Prize announcement, and to Phil Walker and Ed Haagen's quick-time movies of the dentition.

In addition, we have begun providing back issues of *Dental Anthropology* on our Web site as PDF files. The Dental Anthropology Association is making these available as a professional courtesy to all interested parties—the site is *not* password-protected. After downloading onto your computer, these files will open using version 6.0 or later of Adobe Acrobat. Each file is one issue of the journal. We developed these in one of two ways. For the older issues that had not been saved in electronic format, hard copies were scanned (at 300 dpi). The newer issues were generated using Adobe InDesign and then converted to PDF files. The newer issues (from vol. 15 no. 2) contain color figures.

To facilitate downloading, file sizes were, however, aggressively down-sampled. If you have problems with the resolution or encounter other problems with the files, please contact the Editor (eharris@utmem.edu). As of this writing, volumes 13 through 17 are available at our Web site. The older issues will be added over the next few months.

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A Study of Cusp Base Areas in the Maxillary Permanent Molars of American Whites

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ABSTRACT The focus of this descriptive study was to explore the patterns of variation of base crown areas for the four major cusps on the maxillary first and second permanent molars in a cohort of contemporary North American whites of western European descent. A computer-assisted photogrammetric method was used to measure two-dimensional areas of the cusps. Ranking of mean cusp size was the same for M1 and M2, namely protocone > paracone > metacone > hypocone. In concert with field theory, size decreased while variability (CV) increased across this same sequence. Overall area of M1 (97 mm^2) is 13% larger than M2 (86 mm^2) in this sample. Most cusps exhibited significant sexual dimorphism, with greater differences for the distal cusps within a tooth and from M1 to M2. Intercorrelations of cusp areas were notably low (r^2 < 15%) both within and between M1 and M2, suggesting considerable independence in formative rates of each cusp and low morphological integration of these constituents of the occlusal table. Limited comparative material in the literature suggests that cusp areas may valuably extend the quantitative comparisons for genetic and biological studies beyond conventional tooth crown width and length. *Dental Anthropology* 2005;18:22-29.

Much of a molar's morphological complexity occurs on its occlusal surface, yet conventional measurements are made on the later-forming collum of the tooth. Maximum mesiodistal and buccolingual tooth crown diameters and similar dimensions (*e.g.*, Goose, 1963) primarily have been chosen based on their ease of measurement and their repeatability—not on any true biological criterion. Researchers have investigated other sorts of tooth crown variables, notably Biggerstaff (1969a,b) who devised an array of distances, angles, and areas that can be measured on the occlusal table of teeth in the buccal segments. As with some previous researchers (*e.g.*, Biggerstaff, 1975; Corruccini, 1979; Townsend, 1985; Townsend *et al*., 2003; Bailey, 2004), we were motivated to explore the patterns of variation of the occlusal tables of maxillary molars, largely to investigate whether additional information can be gained compared to the conventional lengths and widths of crowns.

Maxillary molars were chosen because their occlusal morphology is a bit simpler than in the mandible and because there is considerable research by embryologists on how the number and arrangement of enamel knots determines a tooth's occlusal morphology. Considerable importance now is attributed to primary and secondary enamel knots that direct the folding of the inner enamel epithelium (IEE) that determines a tooth's crown morphology (Jernvall *et al*., 1994; Thesleff *et al*., 2001). Enamel knots are transitory condensations of the IEE that cause growth of that site to cease (thereby creating a presumptive cusp tip) while at the same time promoting cell proliferation of adjacent regions that causes the IEE to fold (Jernvall *et al*., 1994, 1998, 2000; Luuko *et al*., 2003). Regional differences in proliferative rates account for the angularity of cusps, at least at the enamal-dentin interface.

Purpose of the present study, which is predominantly descriptive and exploratory, was to characterize the basal cusp areas of the main cusps on the maxillary first and second molars in a sample of North American whites. Basal cusp area is a term coined by Biggerstaff (1969b) to refer to the two-dimensional area defined by a cusp in occlusal view, demarcated by the major developmental grooves (*e.g.*, Zeisz and Nuckolls, 1949) and ranging to the periphery of the occlusal table. In fact, Biggerstaff actually used polygons defined by several anatomic landmarks as proxies for the anatomic configuration of a cusp area because of the technical difficulties involved in computing the area of a free-form object. Wood and colleagues (Wood and Abbott, 1983; Wood *et al*., 1983) used a planimeter to measure basal cusp areas. More recently, Macho and Moggi-Cecchi (1992), Bailey (2004) and others used computer systems that obviate the tedium of semi-mechanical approaches.

MATERIALS AND METHODS

Data were collected from full-mouth dental casts of adult North American whites. Individuals were phenotypically normal. There were 112 females and 88 males

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in the sample (200 individuals total).

Cusp base areas were measured on the maxillary first and second permanent molars. There were very few third molars in this sample because of the common clinical practice of extracting them prophylactically. Not every tooth was usable because of dental restorations that obscured key morphological features. Restorations were, by far, the predominant reason for excluding teeth, and the comparatively high frequency of restorations on the first molars accounts for the larger usable samples for variables on M2.

A high-resolution digital photograph was taken of each molar individually (described in Harris and Dinh, n.d.). These images were stored on a computer, and data were collected using ProScan 5.0 (SAS Institute, NC). Cusp outlines were traced using the computer's mouse in a fashion analogous to using a planimeter (Wood and Abbott, 1983; Wood *et al.*, 1983). The four main cusps were measured individually (Fig. 1). The fifth cusp (the metaconule[1]; Harris and Bailit, 1980) was also measured, though it occurred too infrequent to permit statistical analysis. When the hypocone was absent, it was scored as "missing," not zero. The base area of Carabelli's trait (*e.g.*, Kraus, 1959; Turner and Hawkey, 1998) was included as part of the area of the protocone because we found it difficult to distinguish the occlusal component of Carabelli's trait from that of the protocone except when this cingular feature exhibited a large separate cusp. Inclusion of Carabelli's trait accounts for the protocone's large coefficient of variation, especially on M2 where the trait (and trait size) is more variable.

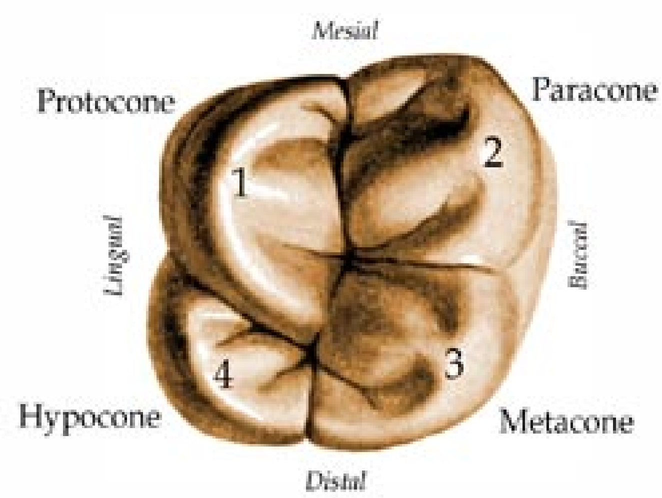

Fig. 1. Terminology used for the maxillary molars. This cusp numbering system was introduced by Gregory (1916); numbering is only used as a shorthand device since this numbering sequence is not the mineralization sequence noted by embryologists (*e.g.*, Kraus and Jordan, 1965).

RESULTS

Descriptive statistics (Table 1) show that the modal cusp base areas is the same as the phylogenetic acquisition of the cusps, namely that the protocone is the largest and the sequence of reduction is protocone > paracone > metacone > hypocone, which is the same ranking of sizes described in texts on contemporary anatomy (*e.g.*, Zeisz and Nuckolls, 1949; Ash, 1993).

Two rankings are of note on the first molar: (1) size of the cusp base area diminishes sequentially from the protocone through the hypocone and (2) size variability (CV) increase in this same sequence. The same patterns of variability hold for the second molar (recalling that we included Carabelli's trait as part of the protocone base area). In addition, as predicted from dental field theory (Dahlberg, 1951), cusp areas on M2 (the later forming tooth) are more variable than homologous features on M1.

Tests for sexual dimorphism (Table 1) show that males characteristically have larger cusp base areas, though not invariably so. The protocone on M1 is not dimorphic ($P = 0.71$) nor is the base area for the metacone ($P = 0.20$). The other two cusps on M1 and all four cusps on M2 exhibit statistically significant sexual dimorphism. On a percentage basis, the overall crown area of M1 is about 5% larger in males ($P < 0.01$) and this difference increases to about 10% for the later-forming M2 ($P < 0.01$).

Correlations were computed between the cusp areas (Table 2). This was done pairwise so the absence of the hypocone on about half of the second molars did not affect the other sample sizes. The weakness of the correlations seems striking; the strongest correlations are only on the order of 0.3 to 0.4 and most are appreciably lower. These low correlations are indicative of "loose" morphological integration of the cusps that compose the occlusal tables (Olson and Miller, 1958). Correlations between cusps on M1, the pole tooth, achieve statistical significance because of the fairly large sample sizes, but they explain little of the variation between areas (all with $r^2 < 15\%$). There is no discernible patterning of the correlations within M1 or within M2. Correlations are even smaller for the M2 comparisons than on M1.

Comparing between M1 and M2, the correlations are no stronger between the homologous cusps than for the other pairings, and, again, the explained variation (r^2) between cusp areas on the two molars is invariably less than 15%.

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[1]Mizoguchi (1988:45) correctly notes that this cusp actually is the "tuberculum accessorium posterius externum" described by Selenka (1898, cited in Korenhof, 1960) that Mizoguchi himself terms the "distobuccal accessory marginal tubercle." The true metaconule is a different feature.

TABLE 1. Descriptive statistics and tests for sexual dimorphism[1]

	Total				Male			Female					
Variable	n	$\bar{x}$	sd	CV	n	$\bar{x}$	sd	n	$\bar{x}$	sd	%SD	F Ratio	Prob > F
						Maxillary First Molar							
Protocone	160	32.23	4.78	14.83	68	32.40	5.34	92	32.11	4.34	0.9	0.14	0.7109
Paracone	160	24.06	3.41	14.18	68	25.36	3.46	92	23.09	3.05	9.8	19.25	< 0.0001
Metacone	160	21.46	3.09	14.41	68	21.83	3.14	92	21.19	3.05	3.0	1.65	0.2005
Hypocone	160	19.35	3.83	19.80	68	20.26	4.28	92	18.68	3.33	8.5	6.90	0.0094
Metaconule	1	4.59	--	--	0	--	--	1	4.59	--	--	--	--
Crown Area	160	96.94	10.45	10.78	68	99.85	11.30	92	94.78	9.25	5.3	9.70	0.0024
						Maxillary Second Molar							
Protocone	183	36.97	7.48	20.22	78	38.50	7.98	105	35.83	6.90	7.5	5.88	0.0163
Paracone	183	25.47	3.65	14.32	78	26.21	3.49	105	24.92	3.68	5.2	5.78	0.0172
Metacone	183	16.07	3.15	19.58	78	16.90	3.56	105	15.46	2.66	9.3	9.81	0.0020
Hypocone	102	14.58	5.29	36.28	43	16.06	5.86	59	13.50	4.59	18.9	6.09	0.0153
Metaconule	2	20.51	11.43	--	2	20.51	11.43	0	--	--	--	--	--
Crown Area	183	85.67	11.90	13.90	78	90.37	14.28	105	82.18	8.26	10.0	23.85	< 0.0001

[1]Descriptive statistics are: sample size (n), arithmetic mean ($\bar{x}$), standard deviation (sd) and coefficient of variation (CV). "%SD" is percent sexual dimorphism calculated as $\left(\frac{\bar{x}_M - \bar{x}_F}{\bar{x}_F}\right)100$. The F ratios test for sexual dimorphism.

The occlusal table of M2 is about 13% smaller than that of the first molar (Table 3), but this summary statistic hides some interesting variations. The mesial pair of cusps (the protocone and paracone) actually is significantly larger on M2 than M1. In contrast, the decreases in average cusp sizes are dramatic for the metacone and hypocone; both basal areas are about one-third smaller on M2. These distal cusps are, however, smaller absolutely than their mesial counterparts, so, the M1-to-M2 difference for the whole occlusal table is a decrease of about 13%. We also included a molar-by-sex interaction term in the ANOVA tests in Table 3, but it was not significant for any variable, which confirms that the size gradients between M1 and M2 are equivalent (proportionate) in males and females.

DISCUSSION

There are several contributors to a cusp's basal area, though little is known about their specific control mechanisms. The number and presumptive spatial relationships of cusps are defined by primary and secondary enamel knots (Thesleff and Jernvall, 1997; Jernvall and Thesleff, 2000; Sharpe, 2001; Thesleff *et al*., 2001). The histological occurrence of enamel knots has been known for over a century (reviewed in Butler, 1956), but their function was recognized only recently. Enamel knots are sites in the stellate reticulum adjacent to the inner enamel epithelium. They are sites without mitotic activity that initiate cusp tip formation at the enamel–dentin interface.

While enamel knots define the number and fundamental arrangement of cusps, there is considerable growth of the tooth from the cap stage (when knots develop) into the bell stage when amelogenesis progresses down the slopes of the cusps and, eventually, the intercuspal regions mineralize, thereby "freezing" the distances between cusps, at least at the enamel-dentin junction. Information on the growth of the teeth (primarily intercuspal distances between the early-forming stable cusps) shows that there are considerable increases in dimensions of the occlusal table during these phases and that the rates of growth differ among cusps, among teeth, and with time (*e.g.*, Butler, 1967a,b, 1968). Butler's data (1967b) for UM1 show that the paracone-metacone distance increases from about 1 mm when the cusps are first discernible to about 4 mm when they have both mineralized. Butler comments that the intercuspal distances

TABLE 2. Pairwise correlations between cusp areas within and between the two maxillary molars[1]

Variable	Variable	n	r^2	r	P Value	tau	P Value
			Within First Molar				
M1 Protocone	M1 Paracone	160	0.042	0.205	0.0095	0.158	0.0031
M1 Protocone	M1 Metacone	160	0.078	0.278	0.0004	0.166	0.0019
M1 Protocone	M1 Hypocone	160	0.059	0.243	0.0020	0.203	0.0001
M1 Paracone	M1 Metacone	160	0.090	0.301	0.0001	0.177	0.0009
M1 Paracone	M1 Hypocone	160	0.110	0.332	< 0.0001	0.223	< 0.0001
M1 Metacone	M1 Hypocone	160	0.132	0.364	< 0.0001	0.241	< 0.0001
			Within Second Molar				
M2 Protocone	M2 Paracone	183	0.080	0.283	0.0001	0.176	0.0004
M2 Protocone	M2 Metacone	183	0.001	0.029	0.6974	0.025	0.6198
M2 Protocone	M2 Hypocone	102	0.032	0.179	0.0719	0.056	0.4050
M2 Paracone	M2 Metacone	183	0.077	0.278	0.0001	0.182	0.0003
M2 Paracone	M2 Hypocone	102	0.005	0.073	0.4669	0.080	0.2313
M2 Metacone	M2 Hypocone	102	0.029	0.171	0.0856	0.120	0.0749
			Between Molars				
M1 Protocone	M2 Protocone	141	0.050	0.224	0.0076	0.163	0.0041
M1 Protocone	M2 Paracone	141	0.091	0.302	0.0003	0.215	0.0002
M1 Protocone	M2 Metacone	141	0.035	0.187	0.0264	0.139	0.0148
M1 Protocone	M2 Hypocone	76	0.060	0.246	0.0325	0.190	0.0151
M1 Paracone	M2 Paracone	141	0.107	0.327	0.0001	0.219	0.0001
M1 Paracone	M2 Protocone	141	0.004	0.064	0.4498	0.030	0.5953
M1 Paracone	M2 Metacone	141	0.065	0.255	0.0023	0.170	0.0028
M1 Paracone	M2 Hypocone	76	0.043	0.208	0.0714	0.087	0.2679
M1 Metacone	M2 Protocone	141	0.022	0.147	0.0821	0.092	0.1063
M1 Metacone	M2 Paracone	141	0.121	0.348	< 0.0001	0.241	< 0.0001
M1 Metacone	M2 Metacone	141	0.155	0.394	< 0.0001	0.318	< 0.0001
M1 Metacone	M2 Hypocone	76	0.123	0.351	0.0019	0.205	0.0089
M1 Hypocone	M2 Protocone	141	0.002	0.045	0.5943	0.011	0.8459
M1 Hypocone	M2 Paracone	141	0.050	0.224	0.0076	0.180	0.0016
M1 Hypocone	M2 Metacone	141	0.108	0.329	0.0001	0.238	< 0.0001
M1 Hypocone	M2 Hypocone	76	0.149	0.386	0.0006	0.311	< 0.0001

[1]The Pearson product-moment correlation coefficients (r) and coefficients of determination (r^2) are listed, along with Kendall's tau, a nonparametric measure of association. Sample sizes are number of pairs of observations.

have the highest growth rates. "The cusp tips separate more rapidly than can be accounted for by enlargement of the bases on which the cusps stand" (1967b:990). In other words, the cusps migrate toward the sides of the tooth (buccally and lingually) with growth because of faster mitotic rates in the central basin. Additional increases in intercuspal distance and basal cusp area occur after bridging of the cusps because amelogenesis is eccentric, meaning that enamel deposition proceeds "in such a manner that the completed enamel apices are dispersed linguobuccally more than mesiodistally relative to their dentine analogs" (Kraus, 1952). It also is well documented that enamel deposition (amelogenesis) initiates on different cusps at different times and bridging between cusps occurs at different times (Kraus and Jordan, 1965), so the definitive size of cusps at the enamel-dentin junction reflects a collage of events ranging a span of time—where it is likely that this "span" varies among tooth types and among individuals and among populations (Bailey, 2004). Indeed, data collected by Kraus and Jordan (1965) and by Moss and Applebaum (1962) clearly shows these allometric patterns of growth. Similarly, Rosenzweig's (1970) study of crown index (BL/MD times 100) confirms intergroup differences in completed tooth crown shape, along with the trend for males to have larger indices (*i.e.*, greater BL width in comparison to MD length) than females within a group.

Viewed occlusally, cusp area includes the sloping margins of the crowns, down to what, clinically are

TABLE 3. Results of mixed-model ANOVA testing for sexual dimorphism and size difference between cusps on M1 and M2[1]

	Sex Difference			M1-M2 Difference			
Variable	df	F-Ratio	Prob > F	df	F-Ratio	Prob > F	Percent Difference
Protocone	1, 139	2.37	0.1258	1, 139	51.43	< 0.0001	+12.8
Paracone	1, 139	22.50	< 0.0001	1, 139	14.09	0.0003	+5.5
Metacone	1, 139	6.86	0.0098	1, 139	375.61	< 0.0001	-33.5
Hypocone	1, 74	8.83	0.0040	1, 74	126.34	< 0.0001	-32.7
Crown Area	1, 139	21.27	< 0.0001	1, 139	298.91	< 0.0001	-13.2

[1]Sex was included in the model to account for the observed sexual dimorphism in cusp areas. Sex is a fixed effect while the cusp areas on M1 and M2 are a repeated-measure in the ANOVA tests.

termed the heights of contour (Zeisz and Nuckolls, 1949; Ash, 1993). These heights correspond to the bulges (convexities) on the crowns that operationally define the maximum mesiodistal and buccolingual tooth crown dimensions that have been used so extensively in the anthropological study of teeth (Wolpoff, 1971; Swindler, 1976, 2002; Kieser, 1990). These maxima occur at various heights of the crowns depending on tooth type. On human molars, maximum mesiodistal height occurs near the midsection of the crown's height, while buccolingual width occurs close to the gingival margin. Some portions of these crown heights are included in an occlusal projection of a cusp's area even though the collum of the crown mineralizes at some time appreciably later than the occlusal table (Moorrees, Fanning and Hunt, 1963). Macho and Spears (1999) note that there is a mesiodistal gradient among the molars such that first molars have considerably thinner enamel than second and third molars and that the first molar tends to have more sloping (less upright) sides of the crown, buccally and lingually, than the distal molars. One would suppose that these buccal and lingual slopes on M1 would reposition the maximum heights of contour apically and have the effect of increasing occlusal areas when viewing the crown occlusally. Little is known about growth control mechanisms that regulate development of the cervical loop—that region of the crown apical to the occlusal table that progressively undergoes dentinogenesis—and, subsequently, amelogenesis until the crown is complete at the cementoenamel junction (Keene, 1982).

In the present study, we were struck by the low levels of correlation among the basal cusp areas (Table 2). While all of the correlations were positive and many achieved statistical significance because of the large sample sizes, they do not account for much of the observed variation (all $r^2 < 15\%$). The typical interpretation of low biological correlations is that the variables have separate developmental causes (separate etiologies) and that seems to be the case here. The conventional measurement of crown size (*e.g.*, Goose, 1963) has traditionally been viewed as a composite measure of the constituent basal cusp area. The occlusal morphology of a tooth, especially that of a molar, is so distinctive that there rarely is any question as to its arcade, side, or placement in the tooth row. It seems to us that these features have bolstered the supposition that the constituent cusp areas are strongly tied to overall tooth size (also see Garn, 1977). The present study suggests a different scenario: Growth of the basal cusp areas is only weakly coordinated. Low correlations imply weak morphological integration among the main cusps (Olson and Miller, 1958), seemingly because each cusp's growth depends on (largely) independent regulatory mechanisms (Salazar-Ciudad and Jernvall, 2002).

Low correlations among the cusps—weak "morphological integration" of the regions of the occlusal table—are in fact the rule rather than the exception. Biggerstaff commented on these weak associations in his landmark work in this area (1975), and subsequent researchers (Garn, 1977; Corruccini and Potter, 1981; Townsend, 1985; Townsend *et al.*, 2003) have each remarked on it. The consensus is that the constituent regions of the occlusal table show weaker levels of intercorrelation, greater coefficients of variation, greater left-right asymmetry, and lower genetic control (greater environmental variation) than overall crown size. Townsend *et al.* (2003:350) studied intercuspal distances instead of areas, but they concluded equivalently that, "Our finding of high phenotypic variation in intercuspal distances with only moderate genetic contribution is consistent with substantial epigenetic influence on the progressive folding of the internal enamel epithelium, following formation of the primary and secondary enamel knots."

Most of the basal cusp areas on both M1 and on M2 are sexually dimorphic in the present sample of American whites. In fact, percentage dimorphism (Table 1) tends to be greater for these areas than for corresponding sex differences in overall mesiodistal and buccolingual tooth dimensions measured on the same teeth, namely 2.8% and 1.8% for M1 and M2 dimensions mesiodistally and 5.0% and 2.9% for M1 and M2 buccolingually (Harris and Burris, 2003). Again, we attribute the high variability and absence of sexual dimorphism of the protocone on M1 to including the variable size of Carabelli's trait with this cusp. It is of note that the degrees of sexual dimorphism are larger for the second molar whose occlusal table mineralizes around four and a half years of age (Harris and Buck, 2002) than on M1 where mineralization occurs by one-half year. For both molars, the morphologically variable hypocone shows a high degree of sexual dimorphism. This difference in area of the hypocone is part of the morphogenetic field effect, where there is a steeper decline in average size (and occurrence) in females than males (*e.g.*, Moorrees, 1957; Jacobson, 1982).

These findings (Table 1) are at odds with Biggerstaff's finding (1975) that there were "suggestions" of sexual dimorphism in cusp areas but that they seldom attained statistical significance. Biggerstaff did not provide statistics in this regard, but his graphs suggest that, indeed, most means for males and females were within one standard deviation of each other. Subsequent studies of intercuspal distances (Garn, 1977; Townsend, 1985; Townsend *et al.*, 2003) also comment on the low level of sexual dimorphism in these constituent components of crown size.

Biggerstaff's results were hampered by partitioning his sample into small groups based on molar cusp configurations, and he did not actually measure cusp area. Instead, he calculated the areas of polygons defined by several landmarks, none of which was truly peripheral on the occlusal table, so his values variably underestimate "basal cusp area" as viewed occlusally.

The computer-assisted method used in the present study is comparable to that used by Macho and Moggi-Cecchi (1992) to measure cusp areas of maxillary molars of South African blacks (Fig. 2). Analogous to studies of conventional crown diameters (*e.g.*, Richardson and Malhotra, 1975; Jacobson, 1982), the cusp areas of these Sub-Saharan blacks are obviously larger than the present sample of North American whites of western European descent, but not uniformly so. For several cusp areas there is greater sexual dimorphism in the blacks. Protocone size is the same in the two groups for M1 and larger in whites on M2. Paracone areas appear to be equivalent in the two groups, while the metacone and hypocone are appreciably larger in the blacks. Since there is not just a difference in scale between these two groups, additional studies may provide informative patterns of size variation well beyond the simple blacks > whites suggested by overall crown sizes (*e.g.*, Harris and Rathbun, 1991).

Prior studies (*e.g.*, Macho and Moggi-Cecchi, 1992) have asked the somewhat rhetorical question of whether there is uniform (isometric) scaling of cuspal features from M1 to M2 to M3. Obviously, the decisive answer is "no." There are obvious allometric differences. In the present study that compares just M1 and M2 (Table 3), there are highly significant changes for all four-cusp areas. An isometric reduction from M1 to M2 would mean that M2 is merely a "scaled-down" version of M1, the pole tooth. Instead, the protocone and paracone have significantly larger basal areas on M2, while the metacone and hypocone are clearly smaller on M2. The

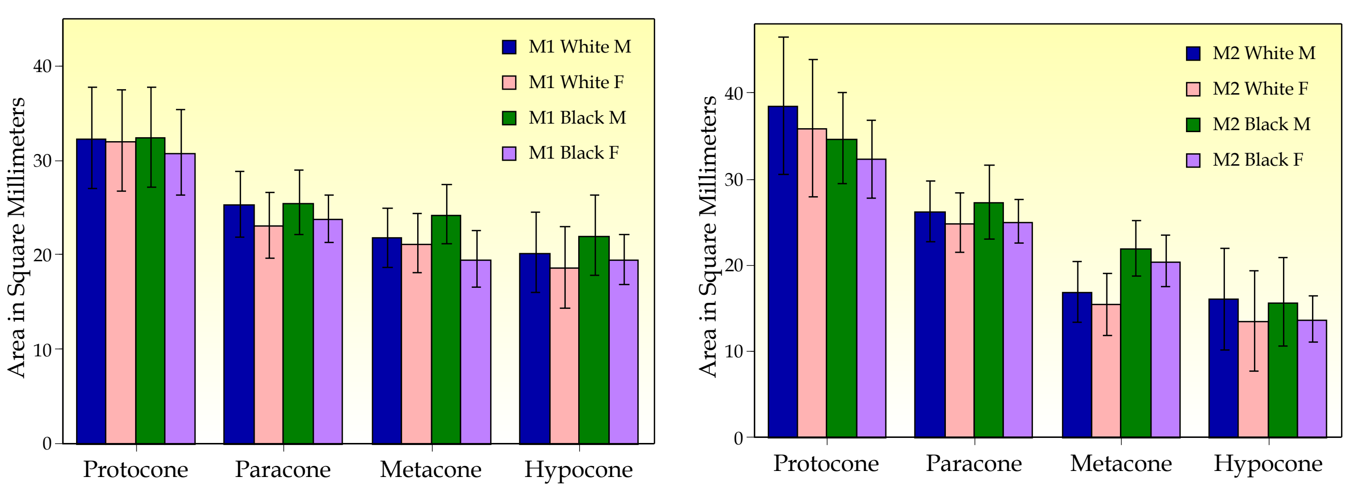

Fig. 2. Average basal cusp areas for the present sample of American whites compared to data published by Macho and Moggi-Cecchi (1992) for South African blacks. Error bars are ±1 standard deviation. Overall crown area was about 3% larger in blacks than whites for M1 and 11% larger for M2.

metacone and hypocone (Table 3) differ in their degrees of size reduction, perhaps because the metacone is part of the molar's comparatively stable trigon, while the hypocone is the sole cusp of the talon in humans (Osborn, 1907; Gregory, 1922). The metacone's variability seems to be expressed wholly as size variation; there was no instance on M1 or M2 where this cusp was absent. In contrast, the hypocone was always present on M1 in some form, but was absent in about half (47%; 66/140) of the M2 sample. Consequently, the size variation calculated here is just for the half of the M2 where the hypocone is present. Other studies that have quantified occlusal areas also have commented on the especial variability of the hypocone (*e.g.*, Biggerstaff, 1975; Peretz *et al.*, 1998; Yamada and Brown, 1998). To note just that M2 has a smaller occlusal table than M1 (a 13% reduction on average) hides the considerable variability within the constituent cusps.

We have explored here some of the biological features of cusp areas on maxillary molars. Our motivation was to extend the battery of biologically (and anthropologically and genetically) useful features that can be studied beyond the hackneyed use of maximum MD and BL crown diameters. Moreover, work by embryologists (*e.g.*, Jernvall and Thesleff, 2000; Salazar-Ciudad and Jernvall, 2002) suggests that regulation of events that define morphology of the occlusal table probably are different than those acting later to form the collum of the crown where conventional diameters are measured, thus providing additional and different biological information. In contrast to the enormously time- and effort-intensive computer methods initiated by Biggerstaff (*e.g.*, 1969a,b), the computer hardware and software now available make the study of crown components comparatively quite feasible.

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Minutes of the 20th Annual Dental Anthropology Association Business Meeting: April 7th, 2005, Milwaukee, Wisconsin

Call to Order:
President Debbie Guatelli-Steinberg called the meeting to order at 7:45 pm. There were 35 members in attendance.

Old Business:
Sally Graver reported on the status of the DAA website. It is up and running, but needs more hits for it to be recognized by Google. She requested that members submit links and other information that can be added to the website.

New Business:
1. Editor's Report: Edward Harris reported that Volume 17 of the Journal was complete, with three issues, each 36 pages. He called for submissions to the journal, including case reports, lab descriptions and newsy reports, as well as scholarly articles. He will be giving PDF versions of past issues to Sally Graver to make available on the Association's Web site.
2. Secretary-Treasurer's Report: Heather Edgar reported that as of April 5th, 2005, the DAA has $3,082.03 in operations funds, and $1,607.75 in the AA Dahlberg prize fund. There are 113 members in the association who are current with their dues, and 145 who are delinquent one or two years. An email is going to be sent to all members (42) who are two three years behind in their membership dues.
3. A.A. Dahlberg Student Prize: The winner of the 2005 was Robin Feeney, for her paper entitled "An investigation of ultrasound methods for the assessment of sex and age from intact human teeth." She received $200, a certificate of award, a year's free membership in the DAA, and will have her article published in the journal [see p. 2]. Sally Graver was named first runner up for her paper entitled "Dental health decline in the Chesapeake Bay, Virgina: The role of European contact and multiple stressors." Sally received $50, a certificate of award, a year's free membership in the DAA, and will have her article published in the journal [see p. 12].

Adjournment:
Debbie Guatelli-Steinberg adjourned the meeting at 8:40 pm. The meeting was followed by a period of socializing around the DAA cash bar.

Submitted by: Heather J.H. Edgar
DAA Secretary-Treasurer

Robin Feeney (*left*) and Sally Graver were awarded Albert A. Dahlberg prizes at the DAA business meeting for their student research projects. Their papers are printed in this issue. (Photograph courtesy of Debbie Guatelli-Steinberg.)

Membership of the DAA

Listed here are the current members of the Dental Anthropology Association and their e-mail addresses. Please contact the Secretary-Treasurer with any additions or corrections.

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