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Bitemarks: Distortion and covariation of the maxillary and mandibular dentition as impressed in human skin

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ABSTRACT

In bitemark analysis the extent of distortion of both maxillary and mandibular arches and how one affects the other has not been studied. A single dentition was used to create 49 bites on unembalmed cadavers. Landmarks were placed on digital images of the bitemarks and scanned images of the biting dentition. A sample of 297 randomly acquired dental models was used for comparison purposes. Geometric morphometric techniques were utilized to statistically describe size and shape change, as well as the correlation between the two arches. Results indicate that the predominant distortion seen was in arch width, at 7–28 times as large as measurement error in the biting dentition and roughly 50% of the variation seen in the random population of dentitions. The correlation of arch width distortion between arches was very low (~0.03). However, the principal patterns of all shape variation did co-vary in the bitemarks produced by the maxillary and mandibular dentition, an effect indicating independence of size and shape distortion. In conclusion, bitemark analysis should be approached with caution when the principal difference between suspects is arch width.

1. Introduction

The discipline of bitemark analysis involves examination of possible tooth patterns imprinted into an object and also comparison of the pattern to the dentition of potential biters. Most commonly, this comparison technique involves analysis of the impression/bruising pattern left by the teeth of the maxillary and mandibular arches in human skin. Skin is a notoriously poor recording medium, however, subject to a wide range of distortion possibilities, an effect generally recognized among bitemark practitioners. The range, correlation, consistency and nature of distortion between arches have not been quantified in any systematic research studies [1,2].

The extent to which distortion in the bitemark produced by one arch predicts distortion in the impression left by the opposing arch has not been previously examined in a detailed manner. This poses questions such as; does the distortion hold for the overall size of the impression, for arch width alone or for metric approaches to quantification of shape? Also how does the degree of distortion in both size and shape compare to the error levels in metric measurements?

In order to explore extent of bitemark distortion in skin, an approach that can statistically evaluate the range and degree of size and shape change associated with distortion is necessary. A well-established method to describe size and shape variation in biological specimens is landmark based geometric morphometric (GM) analysis [3–7]. In GM, landmarks are placed on digital images of specimens. These are captured as coordinates that describe and preserve spatial information. The landmarks can then be extracted and used to express shape changes between specimens in a quantitative and statistical manner, using a set of multivariate statistical techniques.

The use of GM methods as adapted to forensics from their more typical use as research tools in biology and related disciplines, requires homologous structures, which means that all specimens (bitemarks or dentitions) share the same set of *features*, which in forensic terms would be called *class characteristics*. The methods are meant to compare apples to apples, not apples to oranges. GM methods are not suited, for example, for comparing bitemarks produced by humans to those produced by animals. Other metric measures (such as the arch widths, or angular variations) may be readily extracted from landmark measures. Therefore a well-designed study using GM methods captures virtually all metric-based characteristics of a structure.

Shape information embodied in landmark measurements can be visualized by plotting landmark positions in Procrustes

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superimposition, a method of optimally matching one shape to another, a process also known as a registration. This approach uses a metric of the quality of the "fit" of one shape to another, the Procrustes distance, which may be used to summarize variations in populations, to express the degree of similarity of individual specimens, means of populations, or to search for matches between specimens [5,8]. The Procrustes distance is a useful attribute of the method, as it also serves as statistical distance measure, allowing for a wide range of inferential statistical tests.

Traditionally, Procrustes methods remove scale as this method developed from disciplines in which it was desirable to separate shape and size [3–8]. However size information can be preserved, and incorporated with shape, and the results reported using a size-preserving form of Procrustes analysis (Procrustes-SP) [8].

GM methods (non-size preserving) typically use the centroid size (CS) as a measure of size. CS is computed as the square root of the summed squared distances of the landmarks about the central (average) position of all the landmarks [5,8]. This is akin to an average radius of points from their center, and is a linear measure of size, like a length or a width. Procrustes superimposition scales all specimens to a centroid size of 1, so landmark positions and the Procrustes distances between specimens are both dimensionless. Procrustes-SP data retains size information, thus positions are reported in units of length, and the Procruste-SP distance between specimens is also in length units. Both Procrustes and Procrustes-SP approaches were used in this study, particularly as the contrast between results based on each method are informative about the relation of distortion in size to that in shape.

Other statistical tools in the GM framework include principal component analysis (PCA) and partial least squares (PLS) analysis [9–14]. Patterns of related structure in data can be revealed as the principal variations of shape can be plotted and visualized using PCA [9–11]. This allows for determination of which shape aspect is responsible for the most variation, as well as showing relationships among individual bitemarks along these ordination axes. PLS can detect patterns of covariance of specimens, or related shape alterations in different structures, in this case, the bitemarks produced by the maxillary and mandibular dentitions. PLS is a means of studying the covariation of two blocks of multivariate data and examines the correlated departure from the mean shape. It explains covariation much in the same way PCA explains variation. PLS scores in one block of data are the best possible predictors of scores in the other block [9–14]. Though the approach is similar to a regression model, PLS methods explain covariation, not causal predictive relationships as appear in regression models. PLS has often been used to study development correlation in organisms, the analogous use here is to examine the extent of correlation of distortion in the maxillary and mandibular arches.

A previous study applied GM methods to bitemark distortion but only analyzed one arch in a work devoted largely to an examination of the performance of different types of registration methods to bitemarks [15]. A valid criticism of that study would be the lack of investigation of how both the mandibular and maxillary arches interact with skin, and what is the relationship between the two, in both size and shape. The current study is an attempt to statistically quantify both arches together and determine if the distortion in one is correlated to the other. Specifically, using a set of bitemarks produced by a single dentition, the correlation in size distortion (both arch width and centroid size) seen in bitemarks between maxilla and mandible was determined.

The magnitude of the arch width variance appearing in the bitemarks was compared to both the measurement error in the biting dentition and to the range of variance seen in an open population. In addition to size distortion, the range and nature of shape variation in these bitemarks were characterized and examined, as well as the extent to which shape variation was correlated between bitemarks produced by the maxilla and mandible.

2. Methods

Human Subject Review Board Exemption (HSRIB) was granted for this project. Polyvinylsiloxane impressions of the maxillary and mandibular arches were taken from a single volunteer. Models were created using low viscosity epoxy resin to produce strong and durable exemplars that were mounted on a hand held vice grip. The vice grip was instrumented with a load cell to monitor force application. The force applied was consistent with the bite force of the volunteer at 190 N, or roughly 43 pounds. The opening diameter was also set to be consistent with that of the volunteer at 40 mm. The time of application was between 5 and 10 s and then the vice grip was released.

The apparatus was used to inflict 49 bites on human cadavers. The cadavers were unembalmed, stored at 4 °C and allowed to come to room temperature prior to bite creation. The cadavers were acquired based on availability and thus gender, age, cause of death, etc. were not factors in this study. Bites were made on the available dorsal surfaces of the upper arm between shoulder and elbow, dorsal surfaces of the lower arm between elbow and wrist, lateral thoracic wall below the armpit to waist, and the top of the upper thigh and lower leg.

The resulting bites were digitally photographed with an ABFO scale in place. Due to rebound of the bites, all photography occurred within 2 min of infliction as best to maximize the clarity of the teeth in the impressed skin. In order to avoid photographic distortion, the maxillary and mandibular arches were photographed separately as needed.

Landmarks were placed on the digital images using tpsDig academic freeware on the mesial and distal extensions of the 6 anterior teeth as well as the center point of the canines for both the maxillary and mandibular dentitions [16]. The anterior teeth were chosen as it is these teeth that typically impress the skin in a bitemark [1]. Two landmarks were also placed on a number 2 ABFO scale to accurately record size information. This resulted in 14 landmarks for each arch, plus 2 on the scale. The landmarks were then extracted from the images and analyzed with IMP freeware [17]. Linear arch width measurements were extracted from the landmark data, as was the CS measurement of each specimen.

Landmarks were also placed on digitally scanned images of the biter's maxillary and mandibular dental models in the same manner as described for the bitemarks. Concurrently, a sample population of 297 paired maxillary and mandibular dental models were acquired from the University at Buffalo School of Dental Medicine, for use as a comparison sample to illustrate the range of variation in dental size and shape in an open population. This was a sample of convenience and as such age, gender, ethnicity, and socioeconomic status was not recorded. The models were placed on a flat bed scanner and digitally scanned at 300 dpi. Landmark placement was performed and the data extracted as described above. To establish measurement error levels, 10 intra-examiner repeat measurements were made on 3 randomly chosen images of bitemark specimens and 3 scanned dental images. The root mean square (RMS) scatter, a calculation analogous to a univariate standard deviation, was used to describe the resulting error and was reported as the square root of the mean squared distance of specimens about the mean.

3. Results

Arch width distortion in the bitemarks was measured using two different positions on the dentition. The first was the midpoint of the canines and the second was the distal endpoint of the canines. Table 1 describes the averages, standard deviations, coefficients of variation (COV) of these measurements, and of centroid size; as well as the repeat measurements of the biting dentition for both arch width positions. The COV values are about 5% for the bitemarks. Plus or minus 2 sigma was plus or minus 10% in arch width, or about 3 mm. For the repeat measurements, the COV was plus or minus 0.6 to 0.8 percent, or 2 sigma of about 1.5% or 0.3 mm. Thus the variation in arch width or CS in these bitemarks was roughly 10 times the measurement error.

Figs. 1 and 2 illustrate how poorly maxillary and mandibular arch width correlate between the bitemarks produced by the two arches of the single biting dentition. The limited R^2 of upper and lower (~0.3) shows substantial independent variation of arch width in the maxilla and mandible. Therefore width alteration in the two arches is not the same, and changes in one arch width are not predictive of changes in the other.

In contrast, the CS of the maxilla or mandible predicts the corresponding maxillary or mandibular arch width reasonably well. The CS value of each half of the bitemark is well correlated