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Bite-mark analysis: novel tool for ethnicity identification in malaysian population using manual and digital method

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Abstract— Bitemarkanalysis has been used as an ideal tool for recognizing dental features that are unique to the gender, race or ethnicity of a person. But the challenge that most forensic deontologists face in identifying the bite-marks have been accredited to the poor quality, in accuracy or lack of proper bite marks records. digitization in the forensic field, has been progressively evolving, but requires more focus to further advance this method for accurate identification of criminal cases. This comparative cross-sectional study assessed dental arch parameters and tooth parameters using manual method and image analysis digital method with ethnicity Malaysian population. This study showed a definite variationin dental archparameters andtooth parameters in bite-mark analysis between various races of Malaysian population. Comparison of digital method with manual method has been explored in this study.bite-markanalysishasgainedutmostimportanceasasourceofexpertwitnessin the court of law. This study compared bite-mark variations between indian, chinese and malay races of Malaysian population. Importance of digital technology has been re-emphasize dinrelation to bite-mark analysis in forensic science studies

Keywords: Forensic deontology, Bite-mark, Forensic sciences, Ethnicity, Image analysis

1. Introduction

Forensic odontology, a field of forensic science, uses the expertise of a dentist to analyze dental records for the purpose of investigating criminal cases, calamities and in cases of assault or abuse. Highly trained clinical dentists are required to gather information, examine, evaluate and interpret the findings to aid in case investigations. While this subspecialty of dentistry has been around for over decades, recently, it has seen a growing interest among dental professionals to pursue further knowledge in forensic odontology. This can be attributed to cases where identification of missing or deceased persons can be carried out by comparing unique dental evidence of the concerned individuals. One of the most popular methodologies are analyzing bite marks found on various surfaces that are unique to individuals. They have been characterized by the formation of physical end to a series of reactions that occur due to the contact between teeth and surface tissue. [1] The bite marks can be verified with the dental records such as casts or impressions of that individual. The unique characteristics involve the dental arch form and shape of individual teeth.[2] The dental features of an individual can be unique to the gender, race or ethnicity of that person of interest. But the challenge that most dentists faced in identifying the bitemarks have been attributed to the poor quality of the bite marks, inaccuracy or lack of proper dental records. [3]

With the advancement in technology, forensic odontology has evolved to produce more reliable and accurate results in the identification of unknown persons or in criminal justice. [4] This would require evidence-based studies that continue to educate and train forensic odontologists to provide faster and precise evaluation of dental evidence. Along with sound knowledge of the basic craniofacial and dental anatomy, forensic odontologists are required to get acquainted with the latest methods and technology to provide more accurate evidence that can be used in a court of law. This would provide valuable armamentarium to aid in the expanding role of a forensic odontologist in an investigation. [5]

In cases where a forensic odontologist has limited resources, it would be wise to use the common traditional methods [6-8] for bite mark analysis. But with the digitization of dental records, an advanced era of digital bite mark analysis using software have proven to be an effective tool in investigations in the recent years. These software applications in bitemark analysis would provide a more effective tool at assessing every detail of a bite mark that would otherwise be unnoticed by the naked eye. However, none of the computerized innovation strategies have been acknowledged around the globe in forensic sciences due to several parameters such as expense and non -availability of special equipment at the crime scene. [9] With the digitization of dental records, most clinicians use digital radiography, intraoral scanners which can be easily stored in a computer. Additional exploration in this field would be fundamental to advance the space of digital methodology in forensic sciences. These digital records along with the Image analyses software may make it faster in identifying the bite marks by forensic dentists.

Consequently, in situations where there would be lack of digital records or software, dentists still may have to use manual methods to trace bite-marks. In such cases it would be vital to have studies that study methods to easily identify bite marks with similar accuracy to digital methods, or studies that compare efficacy of manual and digital methods. Therefore, the present research was aimed to correlate bite-marks with ethnicity of Malaysian population using manual and image analysis digital method. This study was done to comprehend the manual and digital methods of bite mark analysis with ethnicity in the Malaysian population as well as compare the accuracy between these two methods. This would help to shed a light on the methods of bitemark analysis as well as to understand the drawbacks and efficacy of the method employed by forensic odontologists in further investigations.

2. Techniques

2.1 Samples

Present comparative cross-sectional study was performed on dental study models of patients who had visited the AIMST Dental Center, Kedah, Malaysia during the period from 2016 until date. A total sample of 90 subjects of age group 20-40 years consisting of 30 Malay, 30 Chinese and 30 Indian subjects of Malaysian nationalities were randomly selected irrespective of their gender. Only patients with complete set of permanent dentitions until maxillary and mandibular first molars were included for this study. Patients with developmental abnormality/pathology, ongoing treatment of any form for the present dentition and extremes of chronological ages were excluded. Institutional Ethical clearance from AIMST University Human Ethics Committee (AUHEC/FOD/2021/04) has been obtained prior to the onset of this research.

2.2 Manual and Digital method

In this study, as an initial step, each patient's bite was recorded on a modelling wax using the patient's dental cast. The maxillary and mandibular dental casts were gently pressed onto the modelling wax sheet to record the impression of the dentition. Each impression made on the modelling wax was photographed using a 650D Canon DSLR camera. The wax impressions were used to perform bitemark analysis using two methods- the manual method done on the modelling wax and the digital method done using the photograph of the impression.
The following measurements were included in this study for both the methods: -

- **Intercanine distance:** Measured from the canine cuspal tip on the left side to opposite right side.
- **Intermolar distance:** Measured from the central fossa of the left side molar tooth to the right-side molar tooth.
- **Arch Length:** the median line drawn from Point A (below the inter incisors of the maxillary arch) to the line connecting the distal surface of first molars.
- **Mesiodistal Dimension:** The width at the contact areas (mesiodistal width) of each tooth from 1st molar to the opposite side first molar (12 teeth) in the maxillary and mandibular arch were separately recorded.

The form used for recording the measurements is shown in Annexure 1.

Manual method - In this manual method of bitemark analysis, each wax template was independently recorded by two trained raters who were blinded to the race of the subjects. The raters analyzed the measurements of the bite mark made on the wax sheet manually using a digital caliper, divider and metal scale.

Digital Method – Image Analysis - In the digital method, two trained raters independently recorded each bite mark on the photographs provided to them. The race of the subjects was also blinded to the raters. An ImageJ analysis software was installed and used to determine the digital measurements. Prior to analyzing the image using the ImageJ software, measurement units regarding the image resolution and pixel density were standardized to minimize errors. Photographs of the bite registration templates with ABFO #2 (American Board of Forensic Odontology) scale was digitally scanned for each patient. Each photograph was opened through the ImageJ software and the region of interest was selected using the wand tool. The dental arch parameters and mesiodistal dimensions of individual teeth were recorded using the measurement tool.

Collected data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 15 (IBM, Chicago, IL, USA). For this calibration, descriptive statistics, one way ANOVA and post-hoc tests (using the Bonferroni procedure) for comparison of the mean scores of the measurements for the Indian, Chinese and Malay subjects were performed

(Statistical significance was set at P < 0.05). The comparison of the accuracy of digital method over manual method will be assessed using the intraclass correlation coefficient method.

3. Effects

Assessment of bite analysis measurements using manual method on maxillary templates between Indian, Chinese and Malay subjects showed significant differences in the mean values among various groups of individuals with respect to the parameters – Maxillary Basal Arch Width (Max BAL; *P<0.001*), Maxillary M15 (Max M15; *P= 0.013*), Maxillary M14 (Max M14; *P=0.012*), Maxillary M12 (Max M12; *P<0.001*), Maxillary M22 (Max M22; *P<0.001*), Maxillary M23 (Max M23; *P= 0.032*) and Maxillary M25 (Max M25; *P=0.024*) respectively. [Table 1]

Comparison of the bite analysis measurements using ImageJ software method on maxillary templates between Indian, Chinese and Malay subjects showed significant differences in the mean values among various groups of individuals with respect to all the parameters – Maxillary intercanine distance, Maxillary intermolar distance, Maxillary basal arch width and mesiodistal dimensions of all selected teeth with *P<0.001* for each respectively. [Table 2]

Evaluation of the bite analysis measurements using manual method on mandibular templates between Indian, Chinese and Malay subjects showed significant differences in the mean values among various groups of individuals with respect to the parameters – Mandibular intermolar distance (*P= 0.009*), Mandibular Basal Arch Width (Mand BAL *P<0.001*), Mandibular M33 (Mand M33 *P= 0.008*), Mandibular M32 (Mand M32 *P=0.0023*), Mandibular M31 (Mand M31 *P=0.0036*) respectively. [Table 3]

Contrast of the bite analysis measurements using ImageJ software method on mandibular templates between Indian, Chinese and Malay subjects showed significant differences in the mean values among various groups of individuals with respect to all the parameters – Mandibular intercanine distance, Mandibular intermolar distance, Mandibular basal arch width and mesiodistal dimensions of all selected teeth except tooth 31with *P<0.001* for each respectively. [Table 4] Intraclass correlation analysis was performed to measure the agreement between manual and ImageJ digital measurements in our study. However, the results revealed that the values were less than 0.1, suggesting poor agreement.

4. Dialogue

Bite-mark analysis has been considered to be one of the best tools for distinguishing characteristics as a proof in legal issues with a minor degree of plausibility of errors exhibiting reduction in its reliability. Moreover, forensic scientist must use scientific strategies in a logical manner in future for bite-mark analysis to include them as attestable evidence in the court of law. Thus, in forensic crime scene for testing bite-marks, we should certainly use methods in a more organized way to provide the court of law with reliable evidence. [10] Research also revealed that Bite-mark analysis has been emerging tool to reply to significant scientific questions that aroused in people at the crime location. Bite-mark shapes provide valuable clue or suggestion about a person's acceptance or rejection following examination. Thus, we too accept physical bite mark evidence has always played an imperative role in criminal examination.

In concurrence with this literature, its well accepted that bite mark has been competent enough in withstanding extraordinary environmental conditions. With this awareness, and retaining the importance of manual methods of bitemark analysis, this study was conducted to analyze and compare bitemarks of patients using objective methods - ImageJ analysis software over regularly used manual method at the crime scenes. [11]

Research shed light stating significant differences of mesio-distal width of mandibular left canine tooth structure between Malaysian and Chinese ethnicities and gender. It was also noted that upper left central incisor and lower left lateral incisor could be utilized to determine the ethnicity of Malay and Chinese populations. [12] In addition to the parameters utilized in the above study, our research revealed significant findings ranging from few dental arch parameters to mesiodistal dimensions of individual teeth in manual and digital methods of bitemark analysis. In our study, overall, dental arch parameters (Intercanine distance, Intermolar distance, basal arch length) and mesiodistal dimensions of the selected teeth in maxillary and mandibular templates using digital analysis showed significant differences between Indian with Chinese and Indian with Malay population. However, overall, dental arch parameters (Intermolar distance and Basal arch width) and mesiodistal dimensions of teeth as shown in the results proved significant differences in maxillary and mandibular templates among Indian with Malay and Chinese with Malay population

Previous studies revealed bite marks with gender variation via novel computer-assisted strategies and illustrated its use in forensic sciences. Research also proved this computer-assisted strategies for bite mark analysis to be straightforward, dependable, effectively repeatable, conservative, and less time devouring with maintenance of identity unknown to any participants and members. Partly in concurrence with this study, we also recommend to cease hand-tracing methods and increase the usage of computer-assisted strategies with greater quality and exactness. [13] In accordance with our view, this study also displayed computer-based superimposition technique using Adobe Photoshop software as a precise and novel strategy for bite mark analysis. [14] These studies re-emphasized the importance and usage of computer assisted digital technology for bitemark analysis. Among all the suggested digital technologies, ImageJ software has been chosen for our study considering the user-friendly characteristic with its cost effectiveness and accuracy in the previous studies.

Although previous research showed a mixed opinion with manual and digital technologies, Intraclass correlation analysis in our research stated a poor agreement between both the methodologies. Thus, based on the circumstance and obtainability of digital software's, we recommend forensic odontologist to either proceed manually or digitally at the crime scene as individual findings are significant. However, since this has been the first study in Malaysia for comparing bitemarks within all three racial categories of population and compare the methods with, limited population size, results can be better validated with larger sample size.

3. Conclusion

Bitemarkanalysishasgainedutmostimportanceasasourceofexpertwitnessin the court of law. To our knowledge, this is the first of its kind to correlate the bitemark patterns and mesurements with variations between Indian, Chinese andMalayracesin Malaysian population. ImportanceofDigitaltechnologyhasbeenre-emphasizedinrelationtoBitemarkanalysisinforensicscience studies. To conclude, this study has highlightened all investigators and provide a source for narrowing the process of identification of individuals based on ethnicity in several criminal cases and child abuse cases.

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5. Acknowledgements: Nil

6. Table captions

Table 1:Differences in bite analysis measurements between Indian, Chinese and Malay subjects (Manual Maxillary) (mm)

	Indian Mean (SD)	Chinese Mean (SD)	Malay Mean (SD)	*F*statistic[a] *(df)*	*P* value
Max BAL	39.5 (3.13)	39.2 (3.20)	34.5 (2.06)	28.9 (2, 85)	<0.001[d, e]
Max M15	6.8 (0.68)	6.9 (0.59)	6.4 (0.60)	4.5 (2, 85)	0.013[e]
MaxM14	7.1 (0.82)	7.3 (0.75)	6.8 (0.51)	4.6 (2, 85)	0.012[e]
MaxM12	7.2 (1.09)	7.5 (0.86)	6.3 (0.69)	14.2 (2, 85)	<0.001[d,e]
MaxM22	7.4 (1.06)	7.3 (0.73)	6.3 (0.70)	13.8 (2, 85)	<0.001[d, e]
MaxM23	7.4 (0.98)	7.7 (0.63)	7.2 (0.48)	3.5 (2, 85)	0.032[e]
MaxM25	6.7 (0.71)	7.0 (0.66)	6.5 (0.59)	3.9 (2, 85)	0.024[e]

SD = Standard deviation; df = degrees of freedom

a. One way ANOVA test

b. All 3 pairs of mean scores are significantly different by post-hoc test (Bonferonni procedure)

c. Significant differences between Indian and Chinese
d. Significant differences between Indian and Malay
e. Significant differences between Chinese and Malay

Table 2: Differences in bite analysis measurements between Indian, Chinese and Malay subjects (Digital Maxillary) (mm)

	Indian Mean (SD)	Chinese Mean (SD)	Malay Mean (SD)	*F*statistic[a] *(df)*	*P* value
Max intercanine distance	44.1 (17.85)	69.1 (5.49)	69.6 (4.16)	50.7 (2, 85)	<0.001[c, d]
Max intermolar distance	58.9 (23.66)	92.5 (5.82)	94.9 (6.91)	55.3 (2, 85)	<0.001[c, d]
Max BAL	51.4 (21.13)	78.0 (3.92)	73.0 (3.86)	36.1 (2, 85)	<0.001[c, d]
Max D16	12.3 (6.01)	18.4 (1.55)	20.7 (1.74)	39.6 (2, 85)	<0.001[c, d]
MaxD15	9.1 (3.57)	13.0 (1.37)	14.0 (1.16)	36.6 (2, 85)	<0.001[c, d]
MaxD14	9.3 (3.74)	13.8 (1.28)	14.6 (1.06)	42.6 (2, 85)	<0.001[c, d]
MaxD13	9.5 (4.61)	14.8 (1.18)	15.3 (1.66)	35.2 (2, 85)	<0.001[c, d]
MaxD12	9.3 (4.23)	14.4 (1.83)	13.9 (2.021)	27.6 (2, 85)	<0.001[c, d]
MaxD11	12.2 (4.65)	16.6 (1.19)	17.2 (1.63)	25.3 (2, 85)	<0.001[c, d]
MaxD21	11.3 (4.78)	16.4 (1.27)	17.0 (1.79)	31.3 (2, 85)	<0.001[c, d]
MaxD22	9.8 (4.41)	14.1 (1.18)	13.8 (1.69)	21.5 (2, 85)	<0.001[c, d]

MaxD23	9.8 (4.57)	14.8 (1.11)	14.8 (1.82)	27.8 (2, 85)	<0.001[c, d]
MaxD24	8.9 (3.86)	13.5 (1.02)	14.2 (1.03)	42.1 (2, 85)	<0.001[c, d]
MaxD25	8.7 (3.95)	13.4 (1.48)	13.9 (0.99)	38.5 (2, 85)	<0.001[c, d]
MaxD26	12.8179 (5.57038)	19.3476 (1.40225)	20.7492 (1.55421)	44.416	<0.001[c, d]

SD = Standard deviation; df = degrees of freedom

a. One way ANOVA test
b. All 3 pairs of mean scores are significantly different by post-hoc test (Bonferonni procedure)
c. Significant differences between Indian and Chinese
d. Significant differences between Indian and Malay
e. Significant differences between Chinese and Malay

Table 3: Differences in bite analysis measurements between Indian, Chinese and Malay subjects (Manual Mandibular) (mm)

	Indian Mean (SD)	**Chinese Mean (SD)**	**Malay Mean (SD)**	***F*statistic[a] *(df)***	***P* value**
Mandintermolar distance	41.0 (2.85)	43.7 (3.91)	41.8 (3.15)	4.9 (2,82)	0.009[c, e]
Mand BAL	34.7 (2.01)	34.7 (2.68)	31.0 (2.02)	19.3 (2,82)	<0.001[d, e]
MandM33	6.9 (1.02)	6.7 (0.66)	6.3 (0.53)	5.0 (2,82)	0.008[d]
MandM32	6.1 (0.80)	6.0 (0.76)	5.6 (0.60)	3.9 (2,82)	0.0023[d]

MandM31	5.5 (0.60)	5.6 (0.65)	5.2 (0.62)	3.4 (2,82)	0.036[e]

SD = Standard deviation; df = degrees of freedom

a. One way ANOVA test
b. All 3 pairs of mean scores are significantly different by post-hoc test (Bonferonni procedure)
c. Significant differences between Indian and Chinese
d. Significant differences between Indian and Malay
e. Significant differences between Chinese and Malay

Table 4: Differences in bite analysis measurements between Indian, Chinese and Malay subjects (Digital Mandibular) (mm)

	Indian Mean (SD)	**Chinese Mean (SD)**	**Malay Mean (SD)**	***F* statistic *(df)***	***P* value**
Mandintercanine distance	39.1 (12.71)	58.2 (6.29)	59.1 (5.67)	46.7 (2,82)	<0.001[c, d]
Mandintermolar distance	59.9 (18.80)	86.8 (8.87)	91.4 (6.19)	53.0 (2,82)	<0.001[c, d]
Mand BAL	48.3 (17.06)	72.0 (5.27)	68.9 (3.38)	42.6 (2,82)	<0.001[c, d]
MandD36	11.5 (6.94)	21.1 (1.97)	23.8 (2.11)	63.7 (2,82)	<0.001[c, d]
MandD35	9.7 (4.01)	13.8 (1.02)	15.1 (1.41)	35.4 (2,82)	<0.001[c, d]
MandD34	10.0 (4.09)	14.5 (1.45)	15.5 (1.45)	35.7 (2,82)	<0.001[c, d]
MandD33	10.0 (3.32)	14.3 (1.45)	14.5 (1.74)	34.2 (2,82)	<0.001[c, d]
MandD32	9.7 (3.07)	12.5 (1.25)	13.1 (1.48)	20.8 (2,82)	<0.001[c, d]
MandD41	12.1	11.7	12.2	29.2	<0.001[c, d]

	(2.61)	(1,42)	(1.34)	(2,82)	
MandD42	9.3 (3.54)	12.8 (1.50)	13.3 (1.65)	23.4 (2,82)	<0.001[c, d]
Mand D43	10.1 (3.74)	13.8 (1.75)	14.6 (1.54)	25.9 (2,82)	<0.001[c, d]
Mand D44	10.6 (3.83)	14.7 (2.06)	15.1 (1.39)	25.8 (2,82)	<0.001[c, d]
Mand D45	10.3 (3.98)	13.7 (1.48)	15.1 (1.47)	26.3 (2,82)	<0.001[c, d]
Mand D46	15.7 (5.53)	22.2 (1.63)	23.0 (1.70)	37.9 (2,82)	<0.001[c, d]

SD = Standard deviation; df = degrees of freedom

a. One way ANOVA test
b. All 3 pairs of mean scores are significantly different by post-hoc test (Bonferonni procedure)
c. Significant differences between Indian and Chinese
d. Significant differences between Indian and Malay
e. Significant differences between Chinese and Malay