Analysis of bite marks in food stuffs by CBCT 3D-reconstruction

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1. Introduction

Bite mark analysis plays a vital role in forensic investigations.[1] It is a mark created by teeth, either alone or in combination with other oral structures.[2,3] Bite marks are characteristic of an individual and these are different even in identical twins.[4] This inimitability of an individual's dentition forms the scientific basis for bite mark identification which is used to match a bite mark to suspected perpetrators.

Bite marks are mostly seen in sexual assault, murder and child abuse at the crime site. Bite mark evidence may be found on the body of a living person or a corpse or on objects.[5] It can occur on any part of the body of a victim but most commonly seen on face, neck, arm, breast, legs, buttocks, waist and female genitals.[6] Bite marks can also be seen on other objects, including food stuff like cheese, chocolate, apples or chewing gums, assessment of which can be a major factor leading to conviction of the accused.

Bite marks have a distinct double horseshoe shape pattern showing the anterior teeth of the upper & lower jaw.[7] These marks reveal the peculiar features of individual dentition such as tooth spacing or ridges on the biting surfaces, restorations, as well as missing, broken, chipped, or distorted teeth facilitating identification of a particular individual.[8]

Various methods have been devised for recording of the bite marks, which can be categorized into direct and indirect method. Direct technique involves the use of a model of the suspect's teeth which is then compared to life sized photographs of the bite mark, while in indirect technique dental exemplars with the duplicate of the biting surface of teeth is compared to the injury pattern either manually or using software analysis. The procedure for comparing bite marks is well established and includes measurement and analysis of the pattern, size, and shape of teeth against similar characteristics observed in an injury on skin or a mark left on an object.[9,10] Several methods exist to produce these overlays like hand tracing from dental study casts, wax impression technique, photographic method, radiographic wax impression technique, photocopying and computer assisted overlay generation method.[11–13] Other methods use X-ray film overlays created from radioopaque material applied to the suspect's wax bite. Recently, some authors have reported improved methods for comparative analysis by using computer-based techniques to produce bite mark comparison overlays.[14,15]

Bi-dimensional methods are more commonly used in bite mark analysis. The bi-dimensional (2D) registration of 3Dimensional (3D) structures leads to loss of information. The three factors of the 3-dimensionality involved when a person bites are the curvature of the object, the shape of the biting dentition and the depth of the penetration. Cone Beam Computed Tomography (CBCT) is specially developed for the imaging of the structures related to dentistry and uses relatively small equipment with lower radiation doses at comparatively lower than a conventional CT.[16] The images are obtained in series of DICOM files (Digital Imaging and Communication in Medicine), that can be analyzed through several different software suites[17]. The analysis of bite-marks by an expert is often delayed, even with strict adherence to the guidelines by the ABFO (The American Board of Forensic Odontology). The advantage of using 3D-CBCT over the conventional technique for bite registration is the minimal handling of the object, in turn minimal changes in the original bite pattern found at the crime scene.[18] It avoids the problems resulting from the 2 dimensional (2D) recording process, simplifying the guidelines and reducing errors. Also, it is easier to store and retrieve the data in a 3D computed imaging.[18] Also, 3D system minimizes angular distortions and hence has a potential to create a robust forensic evidence.[17] Thus, CBCT can have an edge over the conventional recording of the bite pattern. Also, the present research is unique as no such study has been conducted so far where mesio-distal dimensions of anterior teeth on human bite marks scan were compared with the mesio-distal dimensions of anterior teeth (at incisal edge) on scans of the dental casts of the individuals.

2. Aim and objective

The aim of this paper was to evaluate ease of using Cone Beam Computed Tomography (CBCT) in studying the bite marks by analyzing the surface and interior of the bitten objects. In this study, CBCT is applied to the analysis of bite marks in foodstuffs, which may be found in a forensic case scenario.

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3. Materials and methods

3.1. Selection of the participants and ethical statement

100 healthy subjects (50 males and 50 females) in the age group of 18–52 years were randomly selected from the out-patient department of the hospital. Individuals having all anterior teeth were included in the study while individuals with missing anterior teeth, chronic periodontitis, mobile anterior teeth and with wasting disease of teeth such as severe attrition of anterior teeth were excluded from the study. All subjects were informed about the study in their understandable language and included in study after taking written consent.

3.2. Bite mark registration and study cast preparation

The selected individuals were asked to bite on apple. Alginate impressions of maxillary and mandibular anterior teeth of every individual were taken. The alginate impression were disinfected by rinsing the impression with gently running water followed by immersion of impression in 5.25% sodium hypochlorite (diluted to 1:10) for less than 10 min. Finally the impressions were thoroughly rinsed with water and casts were poured.

3.3. CBCT scanning

The bitten apples were stored in a refrigerator in a sealed plastic bag within an hour and then were subjected to scan using Carestream CS 9300 CBCT machine. All the images are captured with field of view (FOV) of 11 × 17 cm, a voxel size of 90 and an exposure time of 20 s at 80 kV and 5 mA. The volumetric data were collected. Maxillary and mandibular casts were also scanned individually with same parameters as in bitten apple and volumetric data were collected.

3.4. Construction of 3D images and measurement of mesio-distal dimension of teeth

The volumetric data of both bitten apple and casts were transferred as DICOM file to a computer with Dolphin Imaging 11.9 Premium Software. The 3D images of apple were constructed (Fig. 1) and bite marks of teeth on apple were analyzed and the mesio-distal dimensions of all anterior teeth bite mark were measured and data were collected. The 3D images of both maxillary and mandibular cast were also
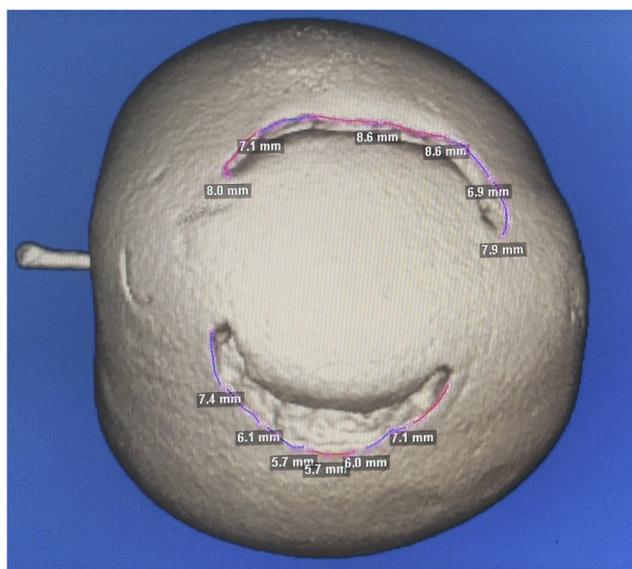

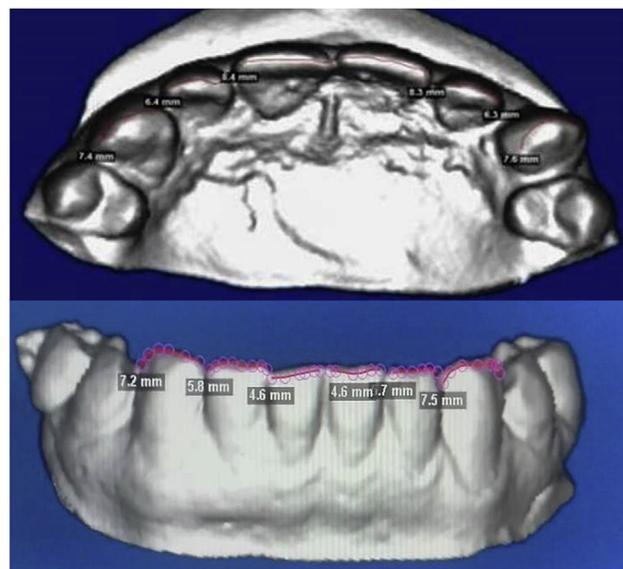**Fig. 1.** 3D image of apple with bite marks of teeth.

Fig. 2. 3D images of maxillary and mandibular cast.

reconstructed (Fig. 2) and mesio-distal dimension (at incisal edge) of all anterior teeth were measured and data were collected.

3.5. Statistical analysis

Categorical variables were presented as number and percentage (%) and continuous variables were presented as mean ± SD. Quantitative variables was compared using unpaired *t*-test between two groups. P value of < 0.05 was considered statistically significant. The data was entered in Micro Soft Excel spreadsheet and analysis was done using Statistical Package for Social Sciences (SPSS) version 21.0.

4. Results

Mesio-distal dimensions at 3 D images of upper and lower anterior teeth on dental cast was statistically significant ($p < 0.05$) for all anterior teeth in males and females except for left and right mandibular lateral incisor teeth [Table 1]. Similarly, mesio-distal dimensions of bite marks of upper and lower anterior teeth on 3 D images of apple was also found statistically significant ($p < 0.05$) for all anterior teeth of both genders except for mandibular left lateral incisor only [Table 2].

On comparing the mesio-distal dimension of individual anterior teeth of cast on 3 D images with mesio-distal dimension on 3 D images of bite mark at apple, only significant value found for the mandibular right canine [Table 3]. Our results reveal that teeth can transfer their unique features to the bitten surface. Identifying characteristics in the bite marks like the shape of the arch, diastema or teeth misalignment could be recognized.

5. Discussion

3D Cone Beam Computed Tomography (CBCT) has revolutionized the field of dentistry in every facet and Forensic Odontology is no exemption. CBCT imaging produces images with sub millimetre isotropic voxels resolution which gives images of 1:1 ratio.[19] This property is valuable in achieving precise measurement of the structures. Hence CBCT was used to measure the dental indentations on the food stuff in present study. Marques J et al. used CBCT for analysis of relative density of bite marks in different foodstuff using Hounsfield unit as internal tool.[20] Only few studies has been done on CBCT base bite mark analysis. Present study was planned to evaluate the ease in utilizing CBCT in indirect method of recording bite marks on food stuff. In our

Table 1
Gender wise comparison of mesiodistal dimension of anterior teeth on cast.

	Sex	N	Mean	Std. Deviation	P value
CAST MAXILLA 11	Male	50	8.4560	.38235	< 0.001*
	Female	50	7.8040	.73595	
CAST MAXILLA 12	Male	50	7.1640	.38638	< 0.001*
	Female	50	6.8000	.58484	
CAST MAXILLA 13	Male	50	7.6760	.59335	0.017*
	Female	50	7.3240	.83166	
CAST MAXILLA 21	Male	50	8.4400	.35225	< 0.001*
	Female	50	7.8600	.64839	
CAST MAXILLA 22	Male	50	7.1360	.38532	0.001*
	Female	50	6.7880	.59544	
CAST MAXILLA 23	Male	50	7.6600	.55032	0.045*
	Female	50	7.3840	.78698	
CAST MAND 31	Male	50	5.5360	.35557	0.008*
	Female	50	5.2960	.51228	
CAST MAND 32	Male	50	6.0840	.44692	0.146
	Female	50	5.9400	.53223	
CAST MAND 33	Male	50	6.9320	.39354	0.001*
	Female	50	6.6600	.43331	
CAST MAND 41	Male	50	5.5320	.29516	0.007*
	Female	50	5.2960	.52643	
CAST MAND 42	Male	50	6.0840	.40575	0.087
	Female	50	5.9160	.55452	
CAST MAND 43	Male	50	6.9080	.35447	0.001*
	Female	50	6.6400	.41008	

Table 2
Gender wise comparison of mesiodistal dimension of anterior teeth on bitten apple.

	Sex	N	Mean	Std. Deviation	P value
APPLE MAX 11	Male	50	8.4120	.53781	< 0.001*
	Female	50	7.8040	.97457	
APPLE MAX 12	Male	50	7.0680	.37112	0.006*
	Female	50	6.7120	.80828	
APPLE MAX 13	Male	50	7.8360	.37020	0.003*
	Female	50	7.4280	.85644	
APPLE MAX 21	Male	50	8.4360	.51021	< 0.001*
	Female	50	7.7680	1.03163	
APPLE MAX 22	Male	50	7.0840	.35419	0.004*
	Female	50	6.7200	.78921	
APPLE MAX 23	Male	50	7.7920	.41396	0.037*
	Female	50	7.5160	.82644	
APPLE MAND 31	Male	50	5.5120	.32741	0.008*
	Female	50	5.2840	.49953	
APPLE MAND 32	Male	50	6.0640	.38320	0.150
	Female	50	5.9440	.44178	
APPLE MAND 33	Male	50	6.9000	.28284	0.037*
	Female	50	6.7440	.43900	
APPLE MAND 41	Male	50	5.5000	.27255	0.016*
	Female	50	5.2960	.52097	
APPLE MAND 42	Male	50	6.0880	.31728	0.033*
	Female	50	5.9200	.44721	
APPLE MAND 43	Male	50	6.9240	.24458	0.013*
	Female	50	6.7560	.40212	

Table 3
Paired comparison of cast and bitten apple.

		Mean	N	Std. Deviation	P value
Pair 1	CAST MAXILLA 11	8.1300	100	.66916	0.774
	APPLE MAX 11	8.1080	100	.84060	
Pair 2	CAST MAXILLA 12	6.9820	100	.52597	0.156
	APPLE MAX 12	6.8900	100	.65080	
Pair 3	CAST MAXILLA 13	7.5000	100	.74019	0.113
	APPLE MAX 13	7.6320	100	.68768	
Pair 4	CAST MAXILLA 21	8.1500	100	.59535	0.550
	APPLE MAX 21	8.1020	100	.87652	
Pair 5	CAST MAXILLA 22	6.9620	100	.52873	0.372
	APPLE MAX 22	6.9020	100	.63548	
Pair 6	CAST MAXILLA 23	7.5220	100	.68969	0.069
	APPLE MAX 23	7.6540	100	.66491	
Pair 7	CAST MAND 31	5.4160	100	.45499	0.193
	APPLE MAND 31	5.3980	100	.43554	
Pair 8	CAST MAND 32	6.0120	100	.49427	0.651
	APPLE MAND 32	6.0040	100	.41583	
Pair 9	CAST MAND 33	6.7960	100	.43390	0.325
	APPLE MAND 33	6.8220	100	.37567	
Pair 10	CAST MAND 41	5.4140	100	.44085	0.245
	APPLE MAND 41	5.3980	100	.42616	
Pair 11	CAST MAND 42	6.0000	100	.49072	0.861
	APPLE MAND 42	6.0040	100	.39490	
Pair 12	CAST MAND 43	6.7740	100	.40443	0.013*
	APPLE MAND 43	6.8400	100	.34171	

the temperature at which bitten apple is stored before scanning through CBCT as in the present study. This is in consistent with findings of Rai et al.[21] in which bite marks in apple demonstrated large secondary distortions.

6. Conclusion

Hence we conclude that the type and consistency of food stuff plays an important role in recording of the measurements of bite marks and inculcation of CBCT in bite mark analysis. CBCT has added advantage over conventional methods due to minimal distortion, better reproduction of the bite marks and permanence of records. Further studies should be called upon using 3D imaging techniques for precise measurements in bite mark analysis.

Conflict of interest statement

None declared.
We, hereby, state that there is no personal or financial conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jobcr.2018.08.006.

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knowledge this is the first study where mesio-distal dimensions of anterior teeth on human bite marks scan were compared with the mesio-distal dimensions of anterior teeth (at incisal edge) on scans of the dental casts of the individuals. One of the limitations of CBCT is its poor soft tissue contrast, hence Dolphin 3D imaging software (Chatsworth, California) was used for measurement of the dental marks on the bitten apple. Apple was selected over other food stuff items as apple is commonly available fruit in most houses and we can get three dimensional impression of the bite also.

While comparing mesio-distal dimensions we found that the comparison of mesio-distal dimension of anterior teeth on the bitten apple and mesio-distal dimension of teeth on the cast of that individuals were statistically not significant (p > 0.05) except in case of right mandibular canine teeth. This discrepancy could be avoided by controlling

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