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PAPER

ODONTOLOGY

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Accuracy and Reliability of Cone Beam Computed Tomography of the Jaws for Comparative Forensic Identification: A Preliminary Study*

ABSTRACT: Conventional computed tomography is an emerging modality in forensic identification but is not sufficiently accurate for use in dental identification primarily because of problems with metallic dental restoration–induced streak artifact. In this study, the accuracy and reliability of recording forensic information from cone beam computed tomography (CBCT) scans of the jaws when compared to conventional panoramic radiographs has been analyzed under experimental conditions. Information could be recorded with near-perfect repeatability and reproducibility. Information could also be recorded accurately, the sensitivity being 96.6% (95% CI, 95.1–98.1) and specificity being 98.4% (95% CI, 96.2–100). The metal dental restoration–induced streak artifact was at a level that permitted, in most cases, accurate observations. This is considered an important step in validating CBCT as a tool in comparative dental identification of bodies. It may have a role in mass fatalities and in chemical, biological, radiological, and nuclear incidents, but further studies are required to assess the feasibility of this.

KEYWORDS: forensic science, forensic odontology, cone beam computed tomography, dental identification, mass fatality, disaster victim identification, chemical incidents, biological incidents, radiological incidents, nuclear incidents

Dental identification has been shown to be an accurate and reliable form of forensic identification (1–3). It is considered by INTERPOL one of the primary forms of human identification together with fingerprinting, DNA analysis, and unique medical features, not requiring substantiating evidence from other scientific disciplines.

Radiology has played a vital role in forensic dental identification for many years. Radiographs enhance the visual examination of the victim by revealing the extent and shape of dental restorations, the presence of root canal treatments, the presence of impacted teeth, the presence of intra-bony pathology, and the spatial relationships between tooth roots and other anatomical structures. When there is a putative identity, the convention has been to take conventional radiographs in the mortuary setting that if possible reproduce the areas of interest and image geometry of the antemortem radiographs. This poses a problem in situations where there is no putative identity or antemortem records such as during the early stages of a mass fatality incident. In this scenario, often all bases are covered with bitewing and full-mouth periapical radiographs being taken of each victim at the initial body examination (4).

Recently, conventional multislice computed tomography (MSCT) has been used for forensic identification (5). It has been used successfully to acquire about 60% of the information required for the physical description in section D of the INTERPOL disaster identification form (6,7). It has also been used in a mobile setting on a trailer parked outside a mortuary to scan six disrupted bodies while in their body bags following a high-speed road traffic accident. The scans were used to successfully identify possible causes of death and to locate debris both on and in the bodies potentially of evidential value or that may have posed a health and safety risk to those handling the bodies (8).

The advantages of using MSCT in forensic identification have been identified as the ability to reconstruct a variety of images some time after the disaster without the need to revisit the body, the possibility to distribute the work of identification digitally to experts remote from the scene while maintaining evidence continuity, thus reducing the number of specialists required at the scene, a reduction in the exposure of personnel to potentially contaminated bodies, and a reduction in the number of radiological sources necessary within a mass fatality mortuary (7,8).

A role for MSCT in dental identification has also been explored (9). However, problems have been experienced when the victim has metallic dental restorations usually in the posterior teeth (10). These result in streak artifact being produced in the computed images, leading to difficulty in defining the extent and margins of metallic restorations. Attempts have been made to resolve this problem using an extended CT scale with some success in an *in vitro* setting (11), but not when whole skulls were scanned (12).

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Cone beam computed tomography (CBCT) is a developing imaging modality. It uses a cone-shaped X-ray beam centered on a detector panel. The source and detector complete a single rotation around a target, producing a series of two-dimensional (2D) frames. Subsequent software manipulation of the data set allows the formation of a volumetric data set, from which either cross-sectional images or 3D objects can be reconstructed. In the dental forensic identification context, its advantages over MSCT are that first streak artifact may be reduced by geometric adjustments to the X-ray tube and detector projecting metal artifacts out of the occlusal plane (13,14) and second forensically useful 2D images can be reformatted from the original data set (15).

The aim of this study was to evaluate the possible role of CBCT in forensic dental identification by analyzing its accuracy and reliability in recording forensically relevant information when compared to conventional panoramic radiographs.

Materials and Methods

Ethical Approval

This study has been approved by the ethics committee of the University of Glamorgan in South Wales. It has also been presented to the South East Wales Research Ethics Committee who considered ethical approval was not required.

Subject Selection

Subjects for this study were identified from the radiology databases of the University Dental Hospital in Cardiff, South Wales. The databases were searched for patients having had both a conventional panoramic radiograph and a CBCT scan carried out from March 2009 to February 2010.

These patients were divided into three arbitrary age cohorts. Up to 17 years with the objective of capturing subjects in the mixed and early adult dentition, 18–49 years to capture subjects in the adult dentition with few and simple restorative treatments, and then 50 years plus to capture subjects with more complex restorative treatments.

The first 10 patients in each age cohort were selected for the study based first on whether they had both mandible and maxilla scanned and then simply on date order giving a total study number of 30. There were no exclusions.

All of the CBCT scans were taken after the conventional panoramic radiographs, usually within 2 months. The longest time interval between the panoramic radiograph and the CBCT scan was 11 months in a subject in the older age cohort.

The CBCT scans were carried out using the Classic i-CAT with the proprietary viewing software i-CATVision (Imaging Sciences International, Hatfield, PA) using protocols dictated by the patient's clinical condition. The conventional panoramic radiographs were taken with a Sirona Orthophos 3 or a Sirona Orthophos CD (Sirona Dental Systems, Inc., Long Island City, NY) using standard settings. A typical conventional panoramic radiograph and reformatted CBCT scan are shown in Fig. 1.

Data Collection

Anonymized observations were first collected from the conventional panoramic radiographs and recorded on the INTERPOL disaster victim identification form F2. This was followed by a washout period of 4 weeks before the same observations were recorded from the CBCT scans. In order to record the information

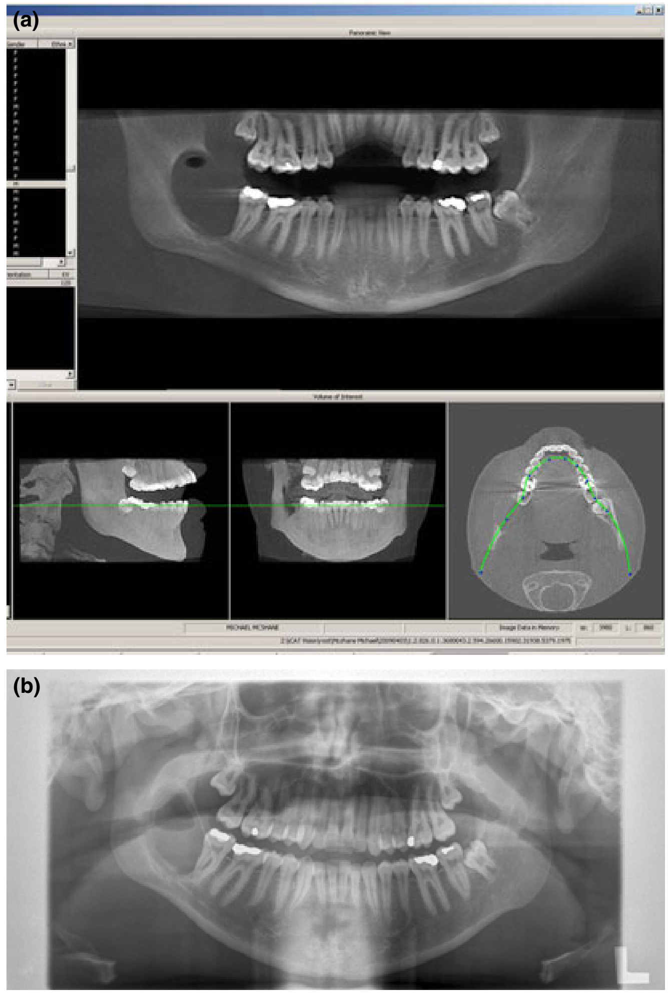

FIG. 1—*(a) Cone beam computed tomography which has been reformatted to show the mandible (with permission from Imaging Sciences International). (b) Conventional panoramic radiograph of the same subject.*

from the CBCT scans, the scan data set was reformatted into a panoramic image. Detailed images of the mandible and maxilla and their associated teeth were optimized by adjusting a contour line using a "drag and drop" facility within the software (Fig. 1). The data collection from each reformatted scan took approximately 20 min.

Observations recorded included teeth present and absent, any dental restorations including their extent and material used, any impacted teeth, and any pathology.

Observation recordings were repeated for the first subject in each age cohort after a washout period of 6 weeks and were also recorded by a second forensic odontologist to provide data for the measurement of inter- and intra-observer agreement. These three subjects were chosen to ensure that subjects with CBCT scans of both maxilla and mandible were included in the assessment of observer agreement, maximizing the number and anatomical range of observations.

Analysis

Statistical methods used to evaluate medical screening tests have been employed in this study with the set of observations recorded from the conventional panoramic radiographs taken as the gold standard. The observations recorded from the CBCT scans were then compared and described as true-positive, true-negative, false-positive, or false-negative observations.

A true-positive observation was a correctly recorded restored tooth including the involved tooth surfaces and whether the restorative material used was metallic or tooth colored. Or a correctly recorded tooth with pathology including the area of the tooth involved.

A true-negative observation was a correctly recorded unrestored tooth either erupted or unerupted, or a correctly recorded missing tooth.

A false-positive observation was an incorrectly recorded restored tooth either over- or underdiagnosing the extent of the restoration or by recording an unrestored healthy tooth as restored or with pathology.

A false-negative observation was the incorrect recording of a restored tooth as unrestored, a tooth with pathology as a healthy tooth, a missing tooth as present, or a tooth present as missing.

From these, the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated and expressed as percentages together with their 95% confidence intervals (16–18).

The reliability of collecting this forensically relevant information from CBCT scans was assessed by measuring the inter-observer agreement or reproducibility and the intra-observer agreement or repeatability. As the observers were making categorical decisions, Cohen's kappa was used as the measure (19) and expressed together with the 95% confidence intervals where appropriate.

Results

The expected distribution of observations within the age cohorts was seen. The highest number of healthy and the lowest number of missing teeth were seen in the youngest age cohort with the reverse seen in the oldest age cohort. There were 685 observations in total (Table 1).

The distribution of true and false negatives and positives across the age cohorts are shown in Table 2. Overall, there were nine false-positive and four false-negative observations.

The false-negative observations were a missed carious lesion in an upper molar tooth, a missed tooth-colored restoration in a lower lateral incisor tooth, a premolar bridge pontic recorded as a crowned tooth, and missed retained roots of an upper molar tooth.

TABLE 1—*Distribution of observations by age cohort and overall.*

	Age Cohort (years)			
Observations	*A* (0–17)	*B* (18–49)	*C* (50+)	Total
Healthy teeth	202	173	63	438
Missing teeth	11	31	79	121
Restored teeth	5	52	64	121
Pathology	1	0	4	5
Total possible observations	219	255	210	685

TABLE 2—*Distribution of true and false negatives and positives between age cohorts.*

	Age Cohort (years)			
Distribution	*A* (0–17)	*B* (18–49)	*C* (50+)	Total/Overall
True negatives	213	204	141	558
True positives	5	45	64	114
False negatives	1	1	2	4
False positives	0	6	3	9

The false-positive observations consisted of five overdiagnoses of the extent of posterior metallic restorations, one underdiagnosis of the extent of a posterior metallic restoration, one diagnosis of caries in a healthy posterior tooth, and two diagnoses of restorations in healthy posterior teeth.

The sensitivity, specificity, PPV, and NPV of recording forensically relevant information from CBCT scans compared with standard conventional panoramic radiographs are shown in Table 3 together with their 95% confidence intervals.

The overall values were all greater than 90%. The lowest being the PPV of 92.7% (90.5–94.8). In the different age cohorts, the only values below 95% were the sensitivity in the youngest age cohort at 83.3% (78.3–88.3) and the PPV in the age cohort 18–49 years at 88.2% (83.8–92.6).

The inter- and intra-observer agreement measurement was based on 103 observations in three subjects. The Cohen's kappa values for intra-observer agreement was 1, indicating perfect agreement, and for inter-observer agreement was 0.96 (95% CI, 0.93–1), indicating nearly perfect agreement (20).

Discussion

In this study, the accuracy and reliability of recording forensically relevant information from CBCT scans has been analyzed over a wide range of age groups.

The Cohen's kappa values indicated perfect or near-perfect intra- and inter-observer agreement, suggesting this method of collecting information is reliable with a high level of repeatability and reproducibility. Even though the kappa values were high, in retrospect, the validity of the assessment of observer agreement could have been improved by randomly selecting a number of separate teeth over a wider range of subjects.

Accuracy of recording was assessed by measurement of the sensitivity, specificity, PPV, and NPV with observations from standard conventional panoramic radiographs taken as the gold standard. This method of analysis was similar to that employed by Kirchhoff et al. in 2008 (12).

In this context, the sensitivity was the proportion of restored teeth or teeth with pathology recorded from the panoramic radiograph also correctly recorded from the CBCT scan. The specificity was the proportion of erupted or unerupted healthy teeth or missing teeth recorded from the panoramic radiograph also correctly recorded from the CBCT scan. The PPV was the probability that restored teeth or teeth with pathology would be correctly recorded from the CBCT scan. The NPV was the probability that a healthy tooth either erupted or unerupted or a missing tooth would be correctly recorded from the CBCT scan.

Overall, the sensitivity was 96.6% (95% CI, 95.1–98.1), the specificity was 98.4% (95% CI, 96.2–100), the PPV was 92.7% (95% CI, 90.5–94.8), and the NPV was 99.3% (95% CI, 97.8–100). This suggests that forensically relevant information can be recorded from CBCT scans with a high degree of accuracy and with few errors in recording the position of teeth or recording teeth with restorations or pathology.

Interestingly, the sensitivity value for the youngest age cohort was relatively low at 83.3% (95% CI, 78.3–88.3). On closer examination, this was a reflection of the relatively low number of restored teeth and therefore possible true-positive observations in this cohort. Numerically, the single false-negative observation seen was sufficient to suppress the sensitivity value to 83.3%.

The overall sensitivity value compares favorably to the study by Kirchhoff et al. (12) in 2008 who reported a sensitivity of 88.2% when assessing the information recorded from reformatted

TABLE 3—*Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) by age cohort and overall.*

	Age Cohort (years)			
Analysis	*A* (0–17)	*B* (18–49)	*C* (50 +)	Total/Overall
Sensitivity (95% C.I.)	83.3% (78.3–88.3)	97.8% (95.8–99.7)	97.0% (94.6–99.3)	96.6% (95.1–98.1)
Specificity (95% C.I.)	100%	97.1% (92.3–100)	97.9% (94.5–100)	98.4% (96.2–100)
PPV (95% C.I.)	100%	88.2% (83.8–92.6)	95.5% (92.1–98.9)	92.7% (90.5–94.8)
NPV (95% C.I.)	99.5% (93.5–100)	99.5% (97.6–100)	98.6% (95.8–100)	99.3% (97.8–100)

conventional multi-detector CT scans compared to those recorded from direct examination of 10 whole skulls. They concluded that the error rate was unacceptably high and that CT could not be relied upon to provide an accurate and reliable method of forensic dental identification.

The overall PPV at 92.7% (95% CI, 90.5–94.8) also compared favorably to the 88.7% reported in the Kirchhoff study (12). It was however low compared to the other measures of sensitivity, specificity, and NPV found in this study. This was a reflection of the particularly low PPV value in the age cohort 18–49 years at 88.2% (Table 3). The PPV value is dependent on the number of false-positive observations relative to the number of true-positive observations. In this age cohort, there were six false-positive observations compared to three in the older age cohort and zero in the younger age cohort (Table 2). This is slightly unexpected as it might be considered more likely to observe false positives in the older age cohort that had the largest number of restored teeth (Table 1). On reviewing the panoramic radiographs and CBCT scans of these six subjects, it was found that three of these false observations were easily resolved. One was simply an incorrectly recorded observation and two in the same subject were as a result of misdiagnosing what were either tooth-colored restorations or temporary restorations in posterior teeth on the conventional panoramic radiograph. They were in retrospect correctly observed from the CBCT scans. Given these findings, it is likely that the PPV in this age cohort and therefore overall is falsely low.

Reviewing the radiographs and CBCT scans of all the false-positive and false-negative observations, it was found that three of the false positives were explainable as described above and one of the false negatives was explainable owing to overlapping of lower anterior teeth obscuring a tooth-colored restoration on the CBCT scan.

Of the remaining nine false observations, four might have posed a problem in a forensic identification scenario where the conventional panoramic radiograph was taken as a surrogate for the antemortem record and the CBCT as a surrogate for the postmortem record. This is because forensically they represented irreconcilable discordances between the two sets of observations. Having said this, in each of these subjects, the high number of concordant observations would not have led to an identification being discounted based on the single discordant observation. At worst, it would have required a direct examination of the body and possibly a conventional radiograph to confirm the false nature of the CBCT scan observation and therefore the identity.

The review of the false observations also suggested that streak artifact may have played a role in three of them involving posterior metallic restorations, the margins of these restorations being difficult to define in the CBCT scans. Overall, streak artifact was not considered to be a major problem; this is in contrast to most of the studies using MSCT in dental identification where streak artifact has been highlighted as a problem (9,10,12) and is in agreement with the only other study to utilize CBCT in forensic dental identification (13).

It appears from this preliminary study that CBCT could be a potentially useful imaging modality for forensic dental identification. However, it should be remembered that this study took place under ideal conditions with the CBCT scans being of living subjects ideally positioned in the scanner, thus optimizing the quality of the images used. In a forensic setting, the situation would be different with the body having to be placed in a supine CBCT machine with the head and jaws positioned in the exposed volume in order to obtain good-quality images. The feasibility of this scenario needs to be explored. These issues aside, its potential advantages are as follows: (i) Forensically relevant information could be recorded rapidly either within a specialist mortuary or in a temporary mobile mortuary at a disaster scene. (ii) The digital data could be sent electronically to odontologists remote from the scene for examination and archiving. (iii) Conventional radiographic images could be reformatted from the CBCT data set for comparison with antemortem records as and when they are collected without having to revisit the body. (iv) Reduced body contact would be required with the potential to eliminate direct examination of the oral cavity in some cases, a particular advantage in chemical, biological, radiological, and nuclear scenarios where there is a high risk of body contamination or in routine dental identification situations where there has been body deterioration as a result of burning. (v) The need for surgical resection of the jaws to facilitate dental examination in cases of body deterioration would be reduced.

Further studies confirming the accuracy and exploring the feasibility of this as a method for noninvasive dental identification would be useful. These could include using clinical examination of subjects on the day of their CBCT scan together with the conventional panoramic radiograph to produce a composite record to be used as the gold standard. Also, the accuracy of CBCT in dental aging of adolescent and young adult victims should be investigated using the atlas and scoring methods in common use (21–23).

Mobile MSCT has been used successfully in a mass fatality incident, and a protocol for data capture, transfer, reporting, and storage reported (8,24). The authors accepted that they had not demonstrated the ability to acquire dentally relevant images at this time. A future study using supine CBCT together with MSCT in such a "forensically real" incident would be useful in determining the logistics and feasibility of such a combined approach to postmortem body management and identification.

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