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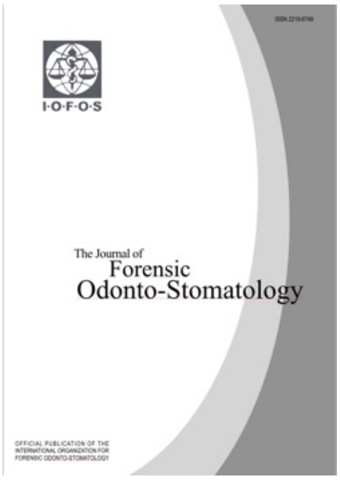

THE JOURNAL OF FORENSIC ODONTO-STOMATOLOGY

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Radiation dose assessment on operator during the dental postmortem procedure using handheld radiograph system

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The authors declare that they have no conflict of interest.

KEYWORDS

Forensic odontology,
Portable handheld radiograph,
Radiation exposure,
Operator safety,
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ABSTRACT
Portable handheld radiograph devices are increasingly common in forensic odontology, particularly in postmortem dental examinations. However, concerns remain regarding radiation exposure to operators handling these devices in mortuary settings. This study aimed to assess the radiation dose to the lens of the eye and fingers of the operator that is exposed to radiation from the NOMAD™ Pro handheld Radiograph. The radiation exposure on the operator of a dental portable handheld radiograph device in the dental postmortem procedure was monitored from March 2020 to February 2021. NanoDot™ OSL Dosimeters (Landauer, IL, USA) were positioned near the eyes and fingers of the operator to estimate the radiation dose. The dosimeters were then analysed using the LAUNDER's MicroStar reader and corrected based on the background reading and calibration parameters. Data from 80 procedures were analysed with the equivalent yearly doses for eyes and fingers were estimated and compared to the International Commission on Radiological Protection (ICRP) recommended limits. Results showed that the annual dose estimation for the lens of the eyes was 1.34 (range 0.56-6.57) mSv/yr while the fingers were 1.52 (range 0.40-5.51) mSv/yr. Radiation exposure to the fingers was slightly higher than exposure to the eyes but remained within requirements of the ICRP dose limits. In conclusion, even though portable radiograph equipment is useful in forensic odontology, operators only receive safe and low levels of radiation exposure. The continuous safe use of these devices in postmortem dental examinations is ensured by appropriate monitoring and adherence to safety procedures.

INTRODUCTION
Dental radiograph imaging is an integral part of forensic odontology investigations. A dental radiograph provides crucial information for establishing the facts of such cases, such as in the identification of unknown human remains using dental features.[1]
In forensic human identification, dental radiographs contribute towards building dental profiles and lead to the identification by comparison of the antemortem and postmortem radiographs.[2–5] During the dental postmortem procedure in the mortuary, radiograph acquisition is a common practice and is usually taken in the form of small film radiographs, such as

periapical or bitewing radiographs.[6] INTERPOL recommends taking a series of periapical and bitewing radiographs as part of the dental postmortem procedure in DVI operations, such as in the event of disasters resulting in mass casualties.[7] These radiographs enable forensic odontologists to collect vital information of the distinctive features of dental anatomy and treatment to aid in identifying unknown human remains.

In dental radiography, a portable, handheld radiograph is now widely used by forensic odontologists.[8] An example of a dental portable handheld radiograph device is the Nomad™.[9] The device is designed to be used by the operator by holding the handle with an outstretched hand, away from the patient, parallel to the ground, and activated at the arm's length distance.[9-10] The device resembles a photographic camera or a shotgun and comes with protective features, i.e. primary protective shielding, a fixed beam limiting device, and a backscatter radiation shield.[9–11]

As the portable radiograph works on a battery source, it offers the advantage of being used at any location compared to the conventional wall-mounted radiograph machine or the portable type activated at a distance used in dental clinics. The device can be used in a mortuary, an operational field, or a remote location with no electricity source.[8] Furthermore, the protective design of the Nomad™ portable radiograph device in the form of a lead shield inside and lead-embedded acrylic protective ring externally creates a maximum protective zone or "area of significant occupancy" for the user against backscatter radiation.[9–12] Minimal exposure to radiation may only be yielded if the device is used according to the manufacturer's recommended use in clinical practice with the operator standing within the area of significant occupancy.[9–11,13] In the mortuary, the deceased body on the autopsy table may be positioned in various, and sometimes unpredictable positions depending on the degree of decomposition or manner of death.[14] The operator may not always be in the area of significant occupancy during the radiographic procedure.[15]

Previous studies indicate the level of radiation exposure to the operator from using the dental portable handheld radiograph device either in a temporary mortuary setting or experimental settings is comparatively low and still within the acceptable or recommended occupational radiation level.[16–18] Previous studies indicate a comparatively low level of radiation exposure within the recommended occupational radiation level to the operator using the portable radiograph device, whether in a temporary mortuary setting[15] or a simulated one.[12,19] Similar observations were noted with different positioning of the operator's hand, body, or the device to the radiated subject.[12,20] Nonetheless, radiation exposure to the operator while using a dental portable handheld radiograph device still raises a concern as the prolonged usage of the device may subject the operator to health risks due to cumulative radiation exposure.[21–23] As such, a baseline radiation exposure level helps to monitor, control, and implement the necessary intervention steps to ensure the safety of the operator.[8,24] Currently, there are no known recorded longitudinal radiation exposure levels to the operator based on actual dental postmortem cases in the mortuary. Thus, the objective of this paper was to establish a baseline radiation exposure to the lens of the eye and fingers of the operator from using NOMAD™ portable handheld radiograph in the mortuary based on forensic dental postmortem cases by the Forensic Odontology Unit of Hospital Kuala Lumpur.

MATERIALS AND METHOD

This cross-sectional study was approved by the National Medical Research Register (NMMR-20-2427-57108). The staff of the Forensic Odontology Unit of Hospital Kuala Lumpur was monitored for radiation exposure while operating the NOMAD™ Handheld Radiograph System (NOMAD™ Pro 2, USA) during the dental postmortem procedure. The radiation exposure doses were collected intermittently between March 2020 and February 2021 during dental postmortem cases in various mortuaries under the Ministry of Health Malaysia. All the periapical radiographs taken in this study were indicated for dental postmortem investigations.

The portable dental handheld radiograph device in this study is regularly calibrated and checked for leakage as part of the maintenance regime. When the portable dental handheld radiograph was used in the dental postmortem procedure, the radiation exposure parameters were fixed at 60 kV and 2.5 mA (adjustment of peak potential and tube current setting is not possible). The operator practised standard protective precautionary steps when taking radiographs for the postmortem procedure. This was carried out by handling the device according to the manufacturer's usage recommendation as much as practically possible, such as standing behind the handheld radiograph device with the installed backscatter shield extended as close as possible to the subject. The operator also wore a lead apron, goggles, and protective collar during the procedure as a standard radiation safety measure. The concept of ALARA (doses should be As Low As Reasonably Achievable) was also applied.

When taking the radiograph(s), the operator was provided with two NanoDot™ Optically Stimulated Luminescence Dosimeters (OSLD) (Landauer, IL, USA) to measure the directly absorbed dose (Figure 1). Before each procedure, the OSLDs were annealed at the Nuclear Medicine Department, Hospital Kuala Lumpur to eliminate any radiation dose stored from previous experiments, radiographic procedures, or from the background radiation of its storage location. Each NanoDot™ OSLD was also pre-analyzed to obtain the background radiation level using LANDAUER's MicroStar InLight® portable reader. Additionally, the portable reader was also calibrated daily to ensure that it produced accurate results.

The NanoDot™ OSLDs were customised into a ring by attaching the OSLD to the stationery plastic ring binder (Figure 2). The two customised OSL Dosimeters were provided to the operator to be worn while taking the radiograph; one ring was attached to the eyeglass frame and one to any one of the fingers of the hand handling the portable handheld radiograph machine (Figure 3). The dental portable handheld radiograph device was usually positioned in proximity to the operator with the operator's hands being approximately within 25 cm from the radiation source output while taking radiographs. The operator stood in any positions practically suitable to the operator that were either the position considered typical as recommended by the manufacturer[1] or positions that deviated or were atypical from the recommended position by the manufacturer (Figure 4).[2,3]

Figure 1. NanoDot™ Optically Stimulated Luminescence (OSL) Dosimeters (Landauer, IL, USA)

Figure 2. The NanoDot™ Optically Stimulated Luminescence (OSL) Dosimeters (Landauer, IL, USA) modified into a ring using ring binder.

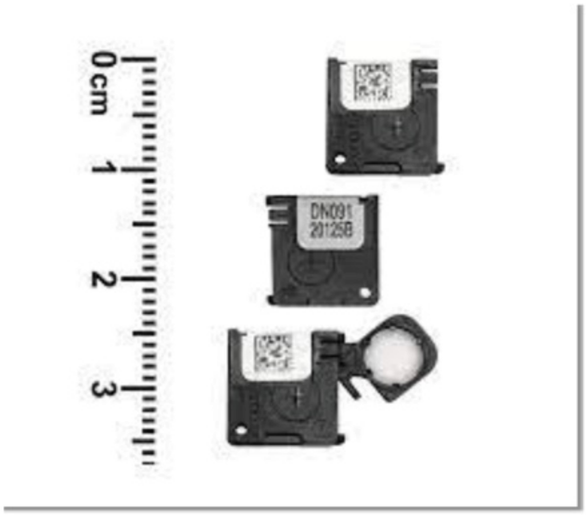
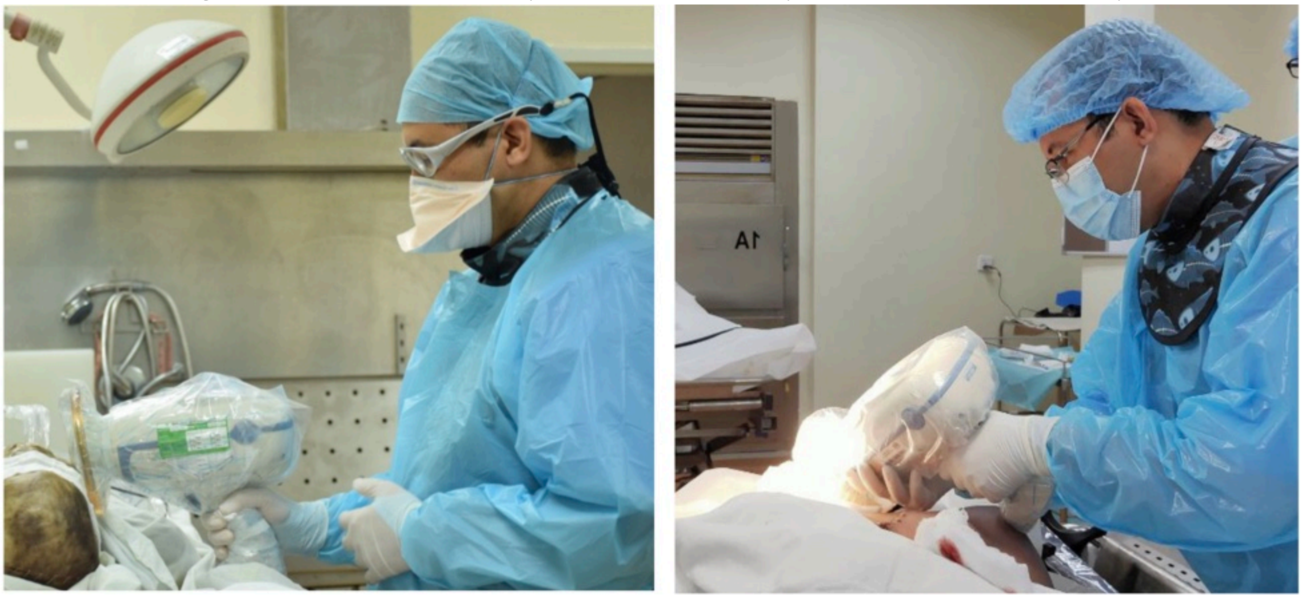


Figure 3. Location of the OSL dosimeters on the eyes (Left) and fingers (Right) of the operator.

Figure 4. The operator in "typical" (Left) and "atypical" position to the body



For each case (or procedure), the number of exposures and total exposure time per case was recorded using a standard form for every dental postmortem procedure. In this study, the total number of exposures is referred to as the total number of radiographs taken during a single dental postmortem procedure.

The NanoDot™ OSLDs were analysed, and the measured dose was corrected based on the background reading and calibration parameter. The measured dose was recorded as an absorbed dose (mGy). Since radiographs were used as the radiation source, the absorbed dose corresponds to the equivalent dose (mSv) as the radiation weighting factor is 1. Therefore, an absorbed dose of 1 mGy in an organ equals an equivalent dose of 1 mSv to that organ.

Data collected was statistically analysed using IBM SPSS Version 20 (IBM Corporation, Armonk, NY, USA). All data were tested for normality of distribution. The annual dose received by the eye and the fingers was then estimated and compared to the occupational exposure dose limits recommended by the International Commission on Radiological Protection (ICRP) for the respective organs.

RESULTS

A total of 112 dental postmortem procedures were performed using the dental portable handheld radiograph device. However, only 80 procedures were included in this study of dosimetry after the protocol deliberation. The exclusion of the procedures was due to either mislabelling, missing data, or data recording errors.

Table 1 shows the profile of the procedures included in this study. The total time for all exposure in this dosimetry study is 93.450s. The exposure times were relatively short, ranging from 0.07 to 0.16 (mean = 0.10) seconds per exposure. The radiation equivalent dose to the finger ranged from 0.0053 to 0.0623 mSv (mean = 0.0296 ± 0.0148 mSv) which was greater than radiation equivalent doses measured for the lens of the eyes which ranged from 0.0058 to 0.0577 mSv (mean = 0.0267 ± 0.0131 mSv) as shown in Table 2.

Table 1. The profile of the study samples

	Total Procedure	Total Exposure	Total time (s)	Time/ Exposure (s) (range)	Mean of Exposure/ Case (range)
Profile of included case	80	916	93.450	0.1 (0.07-0.16)	12 (3-25)

Table 2. Equivalent dose received by the eye and finger of the operator

	Total Exposure	Total time (s)	Total dose (mSv)	Equivalent Dose (mSv) Mean ± SD	Equivalent Dose (mSv) Range	Equivalent Dose (mSv) Median
Eyes	899	91.59	0.855	0.0267 ± 0.0131	0.0058-0.0577	0.0271
Finger	865	87.31	0.946	0.0296 ± 0.0148	0.0053-0.0623	0.0262

Table 2 shows the profile of the equivalent dose received by the operator. As shown in Table 2, the fingers received 865 exposures with a total equivalent dose of 0.946 mSv while the eyes received slightly fewer exposure and an equivalent dose of 0.946 mSv.

Table 3 & Figure 5 show the slightly higher equivalent dose per exposure for the fingers, ranging from 0.00031 to 0.00426 (median = 0.00117) mSv per exposure. Radiation doses measured for the lens of the eyes ranged from 0.00028 to 0.00508 (median =0.00104) mSv per exposure.

Table 4 and Figure 6 show the slightly higher equivalent dose per unit time of the finger, ranging from 0.0160 to 0.0117 (median= 0.0113) mSv/s. The dose per unit time of the eyes ranges from 0.0025 to 0.0693 (median = 0.0109 mSv/s).

Table 4 and Figure 6 show the slightly higher equivalent dose per unit time of the finger, ranging from 0.0160 to 0.0117 (median= 0.0113) mSv/s. The dose per unit time of the eyes ranges from 0.0025 to 0.0693 (median = 0.0109 mSv/s).

Figure 7 shows the dose distribution for the eye lens and finger versus exposure time. The Spearman correlation showed that there was a low correlation between dose and exposure time. There was a wide variation in the dose received by the operator with most of the exposure times per case recorded between 1 to 3 seconds.

Table 5 shows the estimated annual dose to the operator's eye and finger compared to the ICRP's recommended dose limit for eyes(4) and extremities(5).

Figure 5. The box plot of equivalent dose per exposure for eye lens and finger. Symbol (o) indicates outlier of the samples

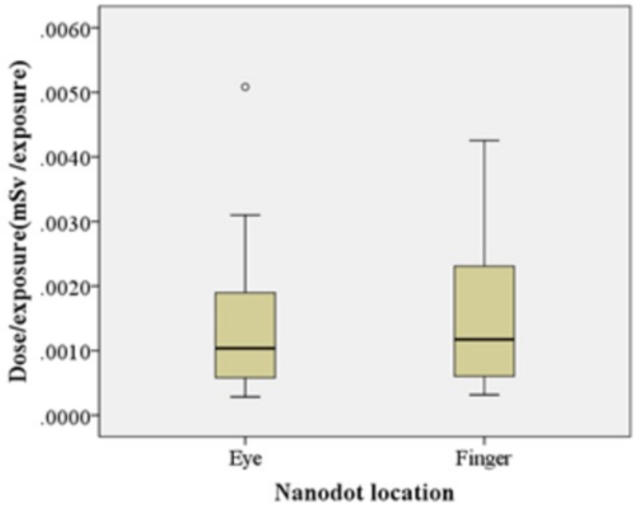


Table 3. Equivalent dose per exposure for the eye and finger

	Equivalent dose/exposure (mSv) Mean ± SD	Equivalent dose/exposure (mSv) Range	Equivalent dose/exposure (mSv) Median
Eyes	0.0014±0.0010	0.0014-0.0010	0.00104
Finger	0.0016±0.0012	0.0016-0.0012	0.00117

Table 4. Equivalent dose per unit time for eyes and finger

	Total time (s)	Dose/time (mSv/s) Mean ± SD	Dose/time (mSv/s) Range	Dose/time (mSv/s) Median
Eyes	91.59	0.0142 ± 0.0130	0.0025-0.0693	0.0109
Finger	87.31	0.0160 ± 0.0117	0.0031-0.0450	0.0113

Figure 6. The box plot of dose per time for eye lens and fingers. Symbol (*) shows outlier of the samples

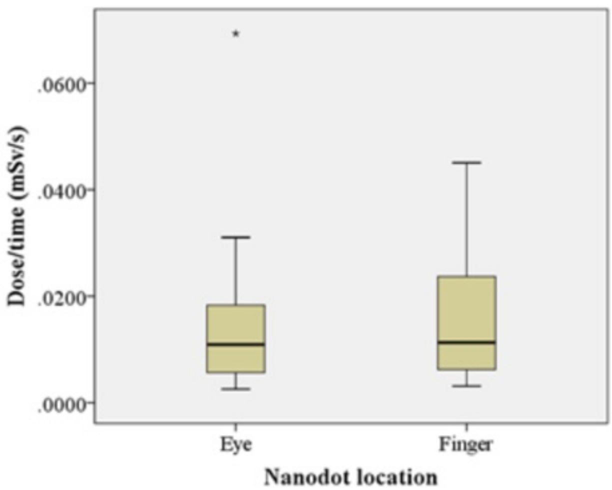


Figure 7. The dose distribution for the eye lens and finger versus exposure time

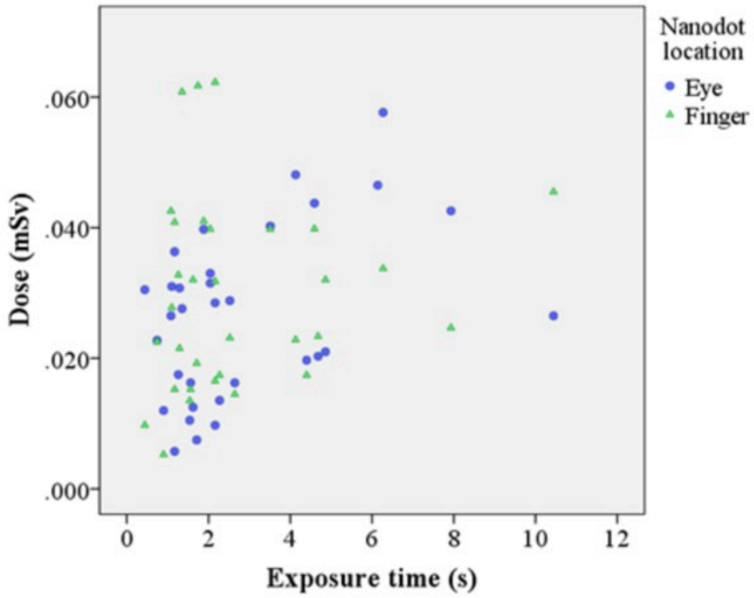


Table 5. Annual dose estimation for the lens of the eyes and finger

	Equivalent dose per year (mSv/yr)	Dose limit occupational exposure
Eyes	1.34 (0.56-6.57)	*20mSv
Finger	1.52 (0.40-5.51)	**500mSv

Recommended dose limit for the lens of the eye; ICRP 118, 2012
***Recommended dose limit for extremities; ICRP 103, 200*

DISCUSSION

This is the first personal dosimetry study analysing radiation dose on an operator handling a portable handheld radiograph device based on a typical Forensic Odontology HKL's postmortem workload. As there were different study designs, the radiation exposures in this study could not be directly compared to the other clinical[25], experimental[12-13,19-20,26] or simulation studies based on the previous exposures in the mortuary.[15] However, the radiation dose in this study was similar to those studies in that the doses to the operator were substantially below the recommended or accepted radiation level either by ICRP or the National Council on Protection & Measurement (NCRP).[18]

According to the exposure profile in this study (3 to 25 exposures, 0.07 to 0.16 seconds per exposure, median 1.036 mSv per case), the same operator will have to perform radiograph acquisition for approximately 1500 dental postmortem procedures within a calendar year to reach the recommended occupational radiation dose limit by ICRP. Presently, it is not necessary to limit the number of procedures per year or the number of radiographs per procedure if adequate radiation protection measures are taken.

One limitation of this study is that it did not compare different positioning techniques with alternative radiographic devices, such as wall-mounted which all require the operator to be in a protected zone or during image acquisition. According to previous research, using a fixed radiographic system reduces operator radiation exposure by increasing distance compared to a handheld radiograph device, which requires close contact with the patient.[27-28]

In this dosimetry study, the limitation included the number of radiation exposures to the finger and lens of the eye was different, with less exposure to the fingers. The difference was due to logistical limitations during the postmortem procedure, of which only the OSLD of either the eye or fingers was available for analysis. Despite the slight difference in radiation exposure, the results showed the fingers received higher exposure compared to the eyes.

This study showed that the annual radiation dose received by the fingers was slightly higher than the eye, and this may be explained by the different distances between the operator's finger and eye to the device. The difference may also be attributed to the positioning of the radiograph machine, which may affect the different exposures. This finding is similar to the findings in the study by Makdissi et al. and Hermsen et al. [15,20]

One of the other possible sources of radiation could be the leakage from the device itself, as reported by the manufacturer.[10] However, as the radiograph device was periodically maintained, the positioning of the organs to the device contributed the most to the radiation exposure.

In this study, the operator took on various positionings of the operator and the radiograph device to the body on the table. The positions were either a modification of the device-operator positioning recommended by the manufacturer [9-10] or similar positions considered as a deviation[20] or atypical exposure situations[12] from the area of significant occupancy described by the manufacturer, which consequently modifies the area of significant occupancy.[10] As this study stresses the effect of the positioning of the portable hand-held radiograph device on the radiation exposure to the operator, the state of the body on the autopsy table may cause a certain unpredictability in positioning the machine itself. Consequently, it is incumbent for the operator to observe and maintain optimum radiation protection measures.

Radiation doses below the recommended level of exposure by ICRP [16,17] or NCRP [18] do not negate the health risk from the radiation exposure to the operator. The annual radiation from a dental portable handheld radiograph device to the operator is shown to be greater than the typical wall-mounted or portable radiograph device operated from what is considered a protected area due to shielding or appropriate distance.[(29)] Hence, despite the low radiation levels, the exposure is still considered unnecessary radiation when compared to the possibly near-zero exposure when an operator can be in the protected area during the radiography acquisition.[30] Significantly, cumulative exposure may still have negative health effects even though radiation doses are still below the recommended annual thresholds. Stochastic risks associated with radiation exposure include a modest but apparent rise of the risk of cancer over an extended period. The regular use of handheld radiograph devices over the years and repeated exposure and regular use may accumulate doses that may pose to long-term health hazards.[31]

The authors opine and recommend that the use of dental portable handheld radiographs in the mortuary to always be aware of the stochastic effects on the operator and subsequently adopt every possible and practical protective measure against unnecessary radiation exposure. Principally, ALARA and the radiation protection concepts should be observed while using the portable handheld radiograph during the postmortem dental procedure. The protective measures may include the use of the lead apron, collar, glove and goggles as they can significantly reduce the radiation exposure to the operator.[8,12,32] Most importantly, while operating the dental handheld portable radiograph device, the backscatter shield should always be properly installed as described and recommended by the manufacturer.[8-10,30-33] The backscatter shield is shown to minimise the radiation exposure to the operator with some studies reporting the radiation as almost ten times higher when used without the shield [15] and others reported a 23-32% reduction in radiation dose to the hand and up to 37% reduction to the waist.[32]

The ALARA approach has evolved into ALADA (As Low As Diagnostically Acceptable) in tandem with a rising conversation about radiation safety. ALADA emphasizes the significance of ensuring adequate image quality to achieve diagnostic criteria, whereas ALARA concentrates on reducing radiation exposure. In forensic odontology, in which radiographs can be potentially used as admissible legal evidence it is important. (Jaju 2015) Accordingly, ALADA compliance signifies that radiation amounts are maximized without affecting the quality of postmortem radiographs that are used for forensic odontology cases.[34]

Furthermore, regular training in taking radiographs of the examined bodies in the mortuary is also essential to avoid radiograph errors such as movement[8] or incorrect sensor positioning, which may increase the risk of producing unusable radiographs. This may result in radiograph retakes, thereby potentially increasing radiation exposure to the operator which is considered unnecessary radiation exposure to the operator. In addition, in the event of mass casualties with multiple bodies requiring examination, such as in DVI, spacing out the period between examinations may be considered a proper measure to minimise cumulative exposure to the operator.

Radiation protection requires continuous operative management. A succeeding study may be required as part of the continuous monitoring of radiation exposure especially when the number of exposures substantially increases from the baseline data recorded in this study. For example, in a DVI operation, it is possible to have continuous exposures or prolonged working hours when multiple bodies need to be examined within a short time.[7,15,35]

The typical dental postmortem procedure in the mortuary may require extra dental personnel to assist the operator during the radiographic procedure.[15] The dose received by the extra personnel will be influenced by the position the assistant stood during radiograph acquisition. Hermsen et al. found that the assistant was exposed the most at the 60° angle from the radiograph primary beam[15] with the least radiation when occupying the area of significant occupancy. [9-10] As such, the assistant or extra personnel during the postmortem procedure is considered to receive significantly low radiation if they are occupying the area of significant occupancy. However, regardless of the position assumed by the extra personnel, adopting similar shielding measures as the operator against radiation exposure should always be considered.

As part of a further radiation protection programme, a visual-spatial mapping may add value for the assistant or extra personnel when occupying the space surrounding the dental portable handheld radiograph in the mortuary. Thus, a further study is underway to map the area of the least radiation exposure based on the radiation doses measured in this study.

This study also highlights the role of medical physicists (radiation protection experts) in radiation protection. Medical physicists can take part in the testing of the device and radiation exposure assessment to minimize unnecessary radiation to the operator. The European Commission proposed in their legislation to involve the medical physicist not only during the acceptance testing of the device but also to test the device throughout its lifetime.[36] In this study, the involvement of the medical physicist assists in the usage compliance of the dental portable handheld radiograph device following the relevant Malaysian radiation regulatory agencies [24] and this practice will likely continue throughout the lifetime of the device. It is noted that current dose limits in the regulations [24] are based on the outdated ICRP [37] recommended dose limit for the eye lens. The authors recommend a revision of the current radiation regulations to be parallel to the global radiation practice such as the revised ICRP recommended limit.[16]

CONCLUSION

To the best of our knowledge, at present, this is the only study that surveys and evaluates the radiation exposure of the operator handling a dental portable handheld radiograph device for the radiograph acquisition based on the typical dental postmortem workload in the mortuary. This study established the baseline dental postmortem procedure profile and correlated radiation profile based on the typical workload for a window of one operation year.

The use of a portable handheld radiograph device NOMAD™ PRO 2 exposes the operator to, albeit low radiation, which is below the accepted or recommended occupational limit. However, despite the substantially low radiation exposure, the exposure still may impose health risks on the operator.

Therefore, there are few recommendations for the operators, such as:

1. Maintaining maximum possible distance from the device by extending the arm.
2. The use of proper radiation protection gear such as lead gloves and goggles.
3. Minimizing the number of repeat exposures by attending proper training.

Meanwhile, for the regulatory bodies and institutions, it is recommended to:

1. Develop standards of operating procedure (SOP) that are specifically intended for the

use of portable handheld radiograph devices and rigorously enforced.
2. Ensure that the portable handheld radiograph devices are well maintained and undergo regular inspections.
3. Monitor radiation exposure data to ensure no unnecessary radiation exposure to the operator.

Consequently, the safe and efficient use of portable handheld radiographs in forensic odontology can be maintained without jeopardizing the health of the operator by integrating careful operator techniques with institutional control and compliance to regulatory standards.

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Orthodontic treatment planning in cleft and craniofacial patients with clear aligners: burden of care and informed consent

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ABSTRACT

Introduction: Orthodontic treatment in cleft lip and palate and craniofacial anomalies is complex and requires a multidisciplinary approach. There are often multiple possible treatment plans. To properly explain and discuss the various options, such as management of frequently missing incisors or the choice between orthognathic surgery and dental compensation, assessment of burden of treatment must be made and adequately communicated to the patients and families.

Patients and methods: 105 patients affected by cleft lip and palate and craniofacial anomalies were retrospectively collected and divided into two groups. The first group included patients whose orthodontic diagnosis involved missing elements, where treatment could be either space closure or space opening. The second group included patients with skeletal discrepancies, who could be treated with dental compensation or with orthognathic surgery. For all patients of both groups two different virtual treatment plans with the Clin Check® software were developed, corresponding to the different treatment possibilities. Clinical aspects which might have influenced treatment choice, such as treatment time, need for extractions, need for prosthetic replacements and need for cooperation were quantified. Logistic regression and Fisher exact test were applied to assess which aspects of treatment led patients to one of the different binary solutions.

Results: Length of treatment was not an aspect which differed between choices, while the need for high cooperation and need for tooth extractions were.

The clear explanation and visual description of advantages and disadvantages of a treatment, seem to help patients in the selection of the expected solution in terms, not only of final occlusal and aesthetic result, but also in terms of burden of care. Though far from sufficient, the visual tool aids patients and families to take an "informed" decision, with significant legal inferences.

Embracing these principles is essential to meet legal standards and foster trust, helping patients make well-informed decisions that align with their personal values and clinical needs. This approach not only respects patient autonomy but also reduces the risk of non-compliance, emotional strain, and potential legal issues, ultimately leading to better therapeutic outcomes and stronger clinician-patient relationships.

INTRODUCTION

Patients affected by cleft lip and palate and craniofacial anomalies need difficult, long, multidisciplinary treatment.

Orthodontic treatment in these patients is generally multifaceted and needs to be coordinated with various surgical interventions. It is usually more complex and in the presence of missing teeth or skeletal discrepancies. There are multiple possible treatment plans with advantages and disadvantages: the burden of care is generally high.

The term "burden of care" refers to the total number of surgeries, orthodontic treatments, appointments and various multidisciplinary rehabilitation procedures that the patient undergoes (World Health Organization, 2002).[1]

To properly discuss the various options, such as the handling of frequently missing incisors or orthognathic surgery versus non-surgical treatment, accurate information, especially in terms of treatment time, is fundamental.[2]

Even an experienced orthodontist has often difficulty in making a correct assessment of the time needed for each treatment option. Spacing due to missing elements (single or multiple), may be treated either by space closure (to avoid the need for implant placement or prosthesis) or space opening (to prepare for prosthetic replacement).

Other patients have maxillo-mandibular skeletal discrepancies, and in such cases, treatment options consist in either a dental compensation or in a surgical-orhodontic treatment. Treatment time and modality may vary significantly.

The ClinCheck® software (Align Technology, California) allows the clinician to develop different treatment plans and provide a forecast, which can be shown and discussed with the patient and his/her family.

Many studies have focused on the reliability of the software in making accurate prediction[3,4] but in the literature the advantage of multiple treatment visualization for a clearer communication with patients and their families has not been described. We believe this aspect should be reported, given that clarity of information during treatment planning is the core of the malpractice aetiology.

Visually describing the different solutions, with timing and additional complexities of different treatment choices may aid patients in taking a more "informed" decision, with significant legal inferences.

AIM

The aim of this study was to describe the possibility with an online software to generate multiple treatment previews, thus helping the clinician together with the family to choose the most adequate treatment plan and provide for a comprehensive, detailed, informed consent.

MATERIALS AND METHOD

We retrospectively collected a sample of 105 patients. affected by cleft lip and palate and craniofacial anomalies treated at the Regional Cleft Lip and Palate Center, Operation Smile, of San Paolo Hospital in Milano.

Patients were divided into two groups. The first group included patients whose orthodontic diagnosis involved missing elements, where treatment could be either space closure or space opening. The second group included patients with skeletal discrepancies, which could be treated with dental compensation or with surgical-orthodontic treatment.

Two different virtual plans were developed for each patient, corresponding to the different treatment possibilities, using ClinCheck® software.

Inclusion criteria: patients affected by cleft lip and palate and craniofacial anomalies; patients with multiple treatment options. Exclusion criteria: non cleft and non-syndromic patients; patients with only one treatment plan.

To understand which aspects of treatment influenced patients' final decision, a quantitative value to the most important clinical aspects was given.

Total treatment time (number of aligners), need for peculiar patient compliance other than wearing the aligners (number of elastics), need for interproximal reduction (IPR), need for placement of an implant at the end of treatment, need for tooth extractions.

A Shapiro-Wilk Normality test was run showing that the data was not normally distributed. Descriptive statistics with means and standard deviations was carried out. To evaluate which parameter most influenced the treatment choices space closure/opening or orthognathic surgery/dental compensation, different statistical analyses were carried out. A logistic regression was carried out for the variables of interest to test whether the mean differences in terms of total orthodontic treatment time or amount of IPR needed (continuous variables) were predictive of the choice between space opening and space closure treatment groups, and between surgical and non-surgical treatment groups (binary outcomes). A Fisher exact non-parametric test was used to test the difference between space opening and space closure treatment groups, and between surgical and non-surgical treatment groups (binary outcomes) depending on the need of elastic wear or not, need for implants/prosthesis or not and need for extractions or not (categorical variables).

Statistical analysis was carried out with Stata 10software (StataCorp., College Station, TX).

RESULTS

1)Space opening/space closure

The patients included in the opening/closing protocol (73.3% of the sample, 77 patients) presented single or multiple agenesis affecting permanent elements. The mean number of missing permanent teeth per patient was 1.6±0,8. Of these, 58.1% had agenesis of one or both lateral incisors.

Closure was selected by 84.4% of patients, while 15.6% chose to be treated with space opening for subsequent prosthesis/implant (Logistic regression, p<0.025).

The average number of aligners (treatment time) in closing and opening options were respectively 49.2±17.5 and 43.9±17.04 and the binary logistic regression showed that treatment time was not a predictor (p>0,05). The average mm of IPR in the opening ClinChecks was 0.38±0.9 mm, in the closing ones was 0.4±0.9 mm (p>0,05). The average use of elastics in the opening ClinChecks was 1.3±1.2, while the average number in the closure was 1.9±1.2 (Fisher test, p>0,05).

These results are shown in table 1.

Table 1. Results after comparing two different treatment options in patients with missing teeth

	Closure	Opening	P value
Aligners (n)	49.5±17.5	43.9±17.04	*ns ‡*
Implants (yes/no)	0	1.3±0.5	**§
Elastics (yes/no)	1.9±1.2	1.3±1.2	*ns§*
IPR (mm)	0.4±0.9	0.3±0.9	*ns ‡*

*† ns not significant, ‡ Logistic regression, § Fisher test.*** P , .01; ** P , .025; * P , .05.*

2) Orthognathic surgery/dental compensation

Patients with a skeletal discrepancy were 26.7% of the sample. For 67.7% of these patients, dental compensation was selected while 32.3% underwent orthognathic surgery (p<0.01). The average number of aligners in surgery and compensation treatment plans were respectively 38.3±13.2 and 43.6±15.4 and the difference resulted statistically non-significant (Logistic regression: p>0.05). Average IPR needed for compensation was 0.84±1.2 mm per patient, against the 0.79±1.4mm IPR expected in pre-surgical ClinChecks. (p>0.05). The average need for extractions for orthodontic compensation was 1.9±1.3, while 0.8±1.2 was the average in orthodontic-surgical treatment plans (Fisher exact test: p<0.025). The average need for compliance with elastics for orthodontic compensation was 1.9±1.3, while 0.8±1.2 was the average in orthodontic-surgical treatment plans (p<0.025). These results are shown in table 2.

Table 2. Results after comparing two different treatment options in patients with skeletal discrepancies

	Surgery	Camouflage	p
Aligners (n)	38.3±13.2	43.6±15.4	*ns ‡*
Surgery (yes/no)	32.3%	67.7%	**§
Extractions (yes/no)	0.16±0.3	0.48±0.4	**§
Elastics (yes/no)	0.8±1.2	1.93±1.3	**§
IPR (mm)	0.79±1.4	0.84±1.2	*ns ‡*

*† ns not significant, ‡ Logistic regression, § Fisher test.*** P , .01; ** P , .025; * P , .05.*

3) Informed consent validity

The aspect of informed consent validity on which this paper focused was the adequacy of the information allowing patients to choose between two very different alternatives.

The validity of informed consent in our clinical context was evaluated through a structured approach involving three key dimensions: (1) completeness of information, ensured by discussing all treatment options, including no treatment, with quantitative data on duration, procedures, and potential risks; (2) patient understanding, evaluated using teach-back methods whereby patients repeated key information to confirm comprehension; and (3) voluntariness, verified by documenting the absence of coercion and allowing adequate time for decision-making. This process was documented in clinical records and supported by visual simulations, aligning with Italian legal standards and European best practices.

Italian Law No. 219/2017 ("Rules on informed consent and advance treatment directives") defines informed consent as the result of clear, comprehensive, and understandable communication, updated at each significant clinical stage, particularly in long-term, multi-phase treatments. The law emphasizes autonomy (Articles 1 and 3), self-determination (Italian Constitution Articles 2, 13, 32) and aligns with Article 3 of the EU Charter of Fundamental Rights.[5]

Among European countries, Italian law is particularly explicit in requiring an ongoing, documented process rather than a one-time signature. Ethical principles—autonomy, beneficence, non-maleficence, and justice—further highlight the need for transparent, empathetic communication. Digital tools such as ClinCheck® improve comprehension, satisfaction, and adherence strengthening trust and the therapeutic alliance.

The results reported show that the patient was informed about the time of treatment, but that this did not influence his/her choice. On the other hand, the need for prosthetic treatment at a later date was a determinant of choice and so were the need for daily cooperation with elastics, the need for extraction and the need for a final orthognathic surgery itself.

DISCUSSION

When multiple treatment plans are possible, even for expert clinicians, the choice for the best option can often be difficult.

This study meets the orthodontist's need to inform the patient as adequately as possible about his/her treatment options, what they entail, the timing of each option, and the clinical commitment, through the help that the software can give to the clinician, who will therefore be able to better advise the patient in his/her choice.

Results show that among the patients with missing teeth, the majority (84.4% of the total) chose space closure treatment, even though space closure treatment was longer. Space closure, avoids the patient the need for dental implants or final prosthesis, and this consideration might have a significant influence on this common choice.[6] The cost and potential biological impact of the prosthesis and the possible failure may lead to the decision for space closure.[7-9]

These results seem to agree with a study published by Naoum et al. in 2021, on healthy subjects, according to which, there is a new trend in treatment of missing teeth, attempting to avoid implant rehabilitation.[10] Space closure also helps to reduce the total treatment burden of care, as space closure allows to end the treatment earlier, while space opening requires the patient to wait until growth completion.

Nevertheless, 13% of the patients with missing teeth, space was opened for the positioning of a dental implant. Some patients explicitly communicated this preference to the clinician, to obtain greater symmetry of the gingival margins in the final smile. The gingival scalloping of patients treated with space closure in the aesthetic area, even after adequate canine shape remodelling, remains always slightly asymmetrical, and this aspect was explained in detail to all patients.[11,12]

In patients with skeletal discrepancy the length of the treatment plans was greater in the orthodontic compensation, with a greater average number of elastics to wear (greater need for collaboration) and a greater need for extractions.

However, these aspects do not seem to have influenced patients' choice.

The patients were informed that surgical-orthodontic treatment guarantees a greater improvement of smile and facial aesthetics compared to orthodontic camouflage.[13] Many patients chose dental compensation, following a speech evaluation, which suggested that maxillary advancement would have meant an increased risk of post-surgical velopharyngeal incompetence, and consequently an increased risk of need for a velo-pharyngoplasty. The "burden of care" would have highly increased. These aspects need to be discussed and may, of course, not be visualized by any software.

The legislation establishes that every patient has the right to be informed in an understandable and complete manner about the diagnosis, possible treatments, predictable consequences, potential risks, and available alternatives. This right to awareness is also accompanied by the right to refuse or modify a treatment plan at any time. For this reason, informed consent is not considered valid if obtained without providing thorough information or if it is acquired coercively, a situation that has often led to legal disputes in the past.

The law places central importance on the concept of the patient's decision-making autonomy, binding the physician to a so-called "therapeutic alliance," a collaborative and transparent relationship that promotes the patient's overall well-being. Such an alliance is particularly relevant in complex, long-term orthodontic treatments, where treatment options often involve multiple surgeries and extended rehabilitations. The ultimate goal is for the patient to be fully aware of the scope of the treatment, its impact on quality of life, and the sacrifices required, both clinically and emotionally.

From a medico-legal and ethical standpoint, presenting clear alternatives, timelines, risks, and benefits is essential to uphold patient autonomy, beneficence, and non-maleficence, strengthening informed consent. For patients with cleft lip and palate, who often undergo prolonged, complex care since childhood, minimizing treatment burden is a key objective, clinically and in terms of quality of life, and should be central to multidisciplinary discussions[14]. In orthodontic management of cleft lip/palate and craniofacial anomalies, the burden of care represents both a clinical and a legal–ethical concern. Offering alternative pathways, supported by quantitative metrics such as treatment length, number of aligners, auxiliary devices, and surgical stages, directly reinforces informed consent.[15]

Forensic and malpractice considerations in orthodontics must be grounded in evidence-based medicine. The most recent systematic reviews, meta-analyses, and guidelines recommend that treatment planning should be based on high-quality comparative data.[16,17]

Across Europe, standards for informed consent vary. In the UK, Montgomery v Lanarkshire Health Board (2015) mandates disclosure of any material risk that a reasonable patient would consider relevant.[18] In Germany, §630e BGB requires tailored and timely communication;[19] in France, the Code de la Santé Publique (Art. L1111-2)[20] ensures consent is "free and informed"; in the Netherlands, the WGBO law formalizes shared decision-making.[21] Compared to these, Italian law stands out for its detailed codification of informed consent as a dynamic, continuous process, integrating both ethical imperatives and medico-legal safeguards.

The core of a valid informed consent is based on the capacity of the patient to understand and make a voluntary decision regarding his treatment, on the adequacy of the information disclosed, on the fact that a clear choice may be expressed, on the disclosure of adequate information regarding the purpose of the proposed treatment, expected outcomes, alternatives, risks.[22-24]

Virtual treatment simulations, allow patients to preview the potential results and planned interventions, reducing the risk of misunderstandings or unrealistic expectations. Tools such as orthodontic planning software make the treatment journey more tangible for patients, fostering a realistic, shared understanding of the timeline, difficulties, and possible outcomes. This increased clarity in communication not only helps protect patients' rights but also serves as a safeguard for the physician, who, through detailed documentation of informed consent, can demonstrate that legal requirements were met.

These rulings demonstrate how Italian jurisprudence considers informed consent as a crucial tool for protecting patients' rights and preventing medical-legal conflicts. They suggest that healthcare professionals adopt an accurate, interactive, and comprehensive communication approach, especially in fields like craniofacial orthodontics, where treatment complexity can generate uncertainty and fears in patients.

CONCLUSION

The use of technological tools, such as the virtual simulation of the treatment, though insufficient by itself, increases the patient's perception of the details, the timing and the alternative to the therapeutic plan. This leads to a free and informed expression of consent to treatment, improving the doctor-patient relationship, and consequently protecting the clinician from most legal action by his/her patients.

The communicative quality of the clinician determines the relationship between doctor and patient. Several literature reviews recognize good communication as the backbone in litigation prevention. The use of technological tools, such as the virtual simulation of what the proposed treatment will be, increases the perception of the details of the therapeutic path, treatment times and any alternatives. This is even more important in cases of high complexity, as often happens in craniofacial malformations. The definition of a treatment plan with possible therapeutic alternatives represents the second medical act after diagnosis. This must be integrated into the context of informed consent which, according to European law, can be acquired in written or videotaped form. This allows the patient to freely and unconditionally express their consent to the treatment.

In conclusion, the legal framework for informed consent encourages healthcare providers to adopt a holistic, patient-centered approach, prioritizing transparent communication, empathetic interaction, and meticulous documentation. This approach not only enhances the patient experience but also strengthens the therapeutic alliance, ultimately reducing the likelihood of litigation. For orthodontists treating complex cases, such as craniofacial anomalies, embracing these principles is essential to both meet legal standards and foster trust, helping patients make well-informed decisions that align with their personal values and clinical needs.

DECLARATION OF PATIENT CONSENT

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

As the database does not contain any identifying information, this study was classified as non-human subject research. Ethical review and approval were waived for this study due to its retrospective nature and the use of anonymized clinical data, in accordance with institutional guidelines and the Declaration of Helsinki

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End-to-end vs. human-defined feature extraction: comparing deep learning approaches for age classification using mandibular third molars

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ABSTRACT

Accurate age classification using mandibular third molar radiographs is crucial for legal and forensic applications. This study evaluated different methods for classifying age as under or over 18 years in a Thai population. We compared three approaches: (i) a traditional human-based method using a modified Demirjian classification adapted for mandibular third molars, (ii) an end-to-end deep learning model in which a convolutional neural network (CNN) directly predicts age group, and (iii) a human-defined feature extraction approach, where a CNN estimates tooth developmental stages that are subsequently used for age classification. The dataset included 3,407 images of individuals aged 14–23 years. The results indicated that the traditional human-based method achieved high specificity (0.99) and a strong Bayes' post-test probability (0.99), but it exhibited low sensitivity (0.45). In comparison, the end-to-end deep learning models showed higher sensitivity (0.65 to 0.74) than the traditional method, along with a specificity of 0.91 to 0.95 and Bayes' post-test probability of 0.93 to 0.95. The human-defined feature extraction approach, which used developmental stages for age determination, achieved an accuracy of 0.88 to 0.92 in developmental stage classification. For age classification, the models demonstrated higher specificity (0.95 to 0.97) and Bayes' post-test probability (0.95 to 0.97) than the end-to-end deep learning method, along with sensitivity ranging from 0.51 to 0.56. Our results indicate that although traditional methods excel in specificity, the human-defined feature extraction approach provides a balanced solution with high specificity and interpretability, suggesting its potential value in clinical practice for age estimation.

INTRODUCTION

Age estimation is crucial in legal contexts, with 18 years widely recognised as the threshold for adulthood, as defined by international standards such as the United Nations Convention on the Rights of the Child.[1] Dental age estimation is an integral part of forensic odontology, providing a reliable method for determining an individual's age by evaluating dental development.[2] Unlike skeletal age estimation, dental age estimation is less affected by environmental factors, enhancing its reliability.[3]

Dental radiographs are a non-invasive, straightforward, and cost-effective method, providing valuable insights into the maturation process of teeth.[4] By the age of 15 years, human teeth, except the third molars, are fully developed,[5] making third molars crucial indicators for age estimation beyond this age. The Demirjian method is a commonly accepted technique for dental age estimation. This involves the analysis of the tooth development patterns using panoramic radiographs to predict an individual's age.[6] Despite its reliability, this method can suffer from observer errors, necessitating rigorous training to minimise inaccuracies.[7]

Deep learning is increasingly used in biomedical imaging, including widespread applications in dental age estimation.[8] Using artificial intelligence (AI) for mandibular third molar classification in legal contexts, previous studies have investigated the application of AI in assessing developmental stages of the mandibular third molar,[9] as well as performing binary age classification at legal thresholds of 14, 16, and 18 years.[10] Although developmental stage classification offers valuable insights, it does not directly provide a dental age. In contrast, end-to-end binary classifiers often function as "black boxes," limiting interpretability and clinical acceptance.[11] Given the legal implications of age estimation, enhancing automation, accuracy, and interpretability is essential for forensic use. A commonly used architecture is the convolutional neural network (CNN), a core component of deep learning. CNNs operate through a hierarchical cascade of layers that automatically extract and refine important features from raw image data. This makes them well-suited for efficient and accurate classification tasks in medical imaging, including radiographic analysis.[12]

This study thus aimed to explore and compare various deep learning approaches for predicting whether individuals are under or over 18 years of age, using mandibular third molar radiographs. We evaluated three approaches: (i) a traditional method using expert assessment of mandibular third molar development based on a modified Demirjian classification, (ii) an end-to-end deep learning model where a CNN directly predicts age group from the radiograph, and (iii) a human-defined feature extraction approach, where a CNN first predicts the tooth's developmental stage, which is then used to classify the age group.

MATERIALS AND METHOD

Data collection

The study was approved by the Faculty of Dentistry Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University (approval no. 60/2022) and the Faculty of Medicine Human Research Ethics, Prince of Songkla University (approval no. REC.66-235-38-2). It was registered with the Thai Clinical Trial Registry (TCTR identification number: TCTR20230519002).

We used a subset of the dataset from the previous study.[9] Digital panoramic radiographs of 1,872 patients (831 male and 1,041 female) were randomly collected from the database of the Dental Hospital of the Faculty of Dentistry, Chiang Mai University, between 2012 and 2019. Patients aged 14–23 years who underwent radiographic examination and had available data on their birth date and date of radiographic examination were included in the study. Patients were excluded whose radiographic images were of poor quality, who had missing or malaligned mandibular third molars (severe buccoversion or linguoversion), or who had developmental anomalies, jawbone pathology, or syndromes affecting the dental development.

Mandibular third molar images were obtained from radiographic examinations, cropped, and rotated to align along the tooth axis at 224 × 336 pixels. Age was calculated by subtracting the birth date from the examination date and used as ground truth. Images were categorised into two groups: patients aged under 18 years and those aged 18 years or older. The data were randomly split into training, validation, and test sets (70:15:15). The training set was used to develop deep learning and human-based prediction models, the validation set to identify the optimal deep learning models and the test set to evaluate both methods. The study workflow and sample distribution are presented in Figure 1 and Table 1.

Traditional human-based approach

The mandibular third molars' developmental stage was assessed by an expert who reported almost perfect intra- and inter-observer agreement in previous studies.[9] The assessment followed a modified version of the Demirjian method,[6] in which the eight developmental stages (Stages A to H), originally proposed for the mandibular first and second molars, were applied to the mandibular third molar, as previously implemented by Duangto et al. (2017) in a Thai population.[13] However, since the patients in our study were aged 14 to 23 and the development of mandibular third molars begin at 7 to 8 years, we observed only the later stages (Stages D to H) (Figure 2). Individuals with mandibular third molars at Stage H were considered 18 years or older, while those at lower stages were considered younger.[14] We evaluated the method's performance using the test set.

Figure 1. Overall workflow of the study (A) data collection workflow (B) research workflow

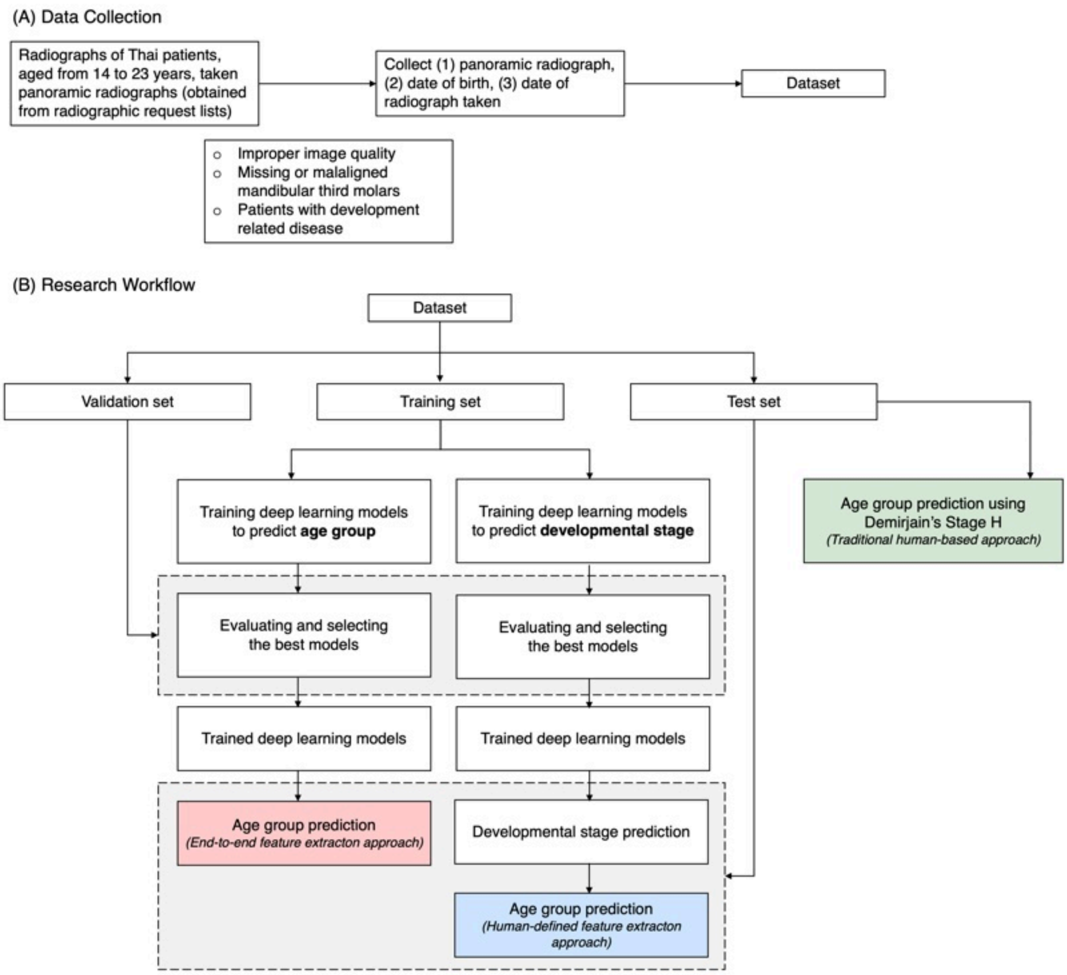
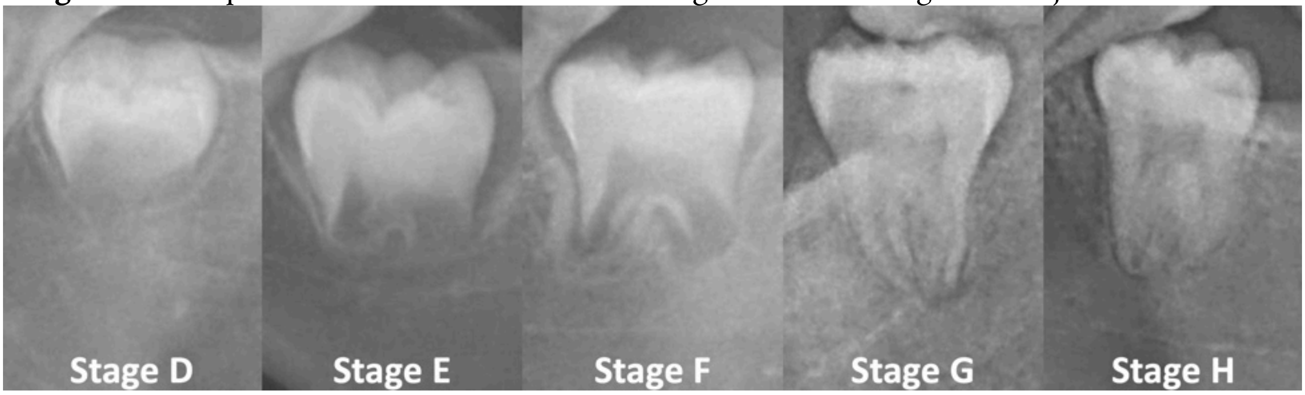


Table 1. Number of mandibular third molar images in the training, validation, and test set

	Training (n=2,385)	Validation (n=511)	Test (n=511)
	n (%)	n (%)	n (%)
Mandibular third molar			
Left	1,180 (49.48)	267 (52.25)	251 (49.12)
Right	1,205 (50.52)	244 (47.75)	260 (50.88)
Age group			
Less than 18 years old	1,259 (52.79)	294 (57.53)	279 (54.60)
More than 18 years old	1,126 (47.21)	217 (42.47)	232 (45.40)
Developmental stage			
Pre-H Stages	1819 (76.27)	384 (75.15)	404 (79.06)
Stage H	566 (23.73)	127 (24.85)	107 (20.94)

Figure 2. Examples of mandibular third molars in Stages D–H according to Demirjian's classification



End-to-end feature extraction approach

For the end-to-end approach, deep learning models were trained to classify individuals as either under or over 18 years of age directly from mandibular third molar radiographs. Several CNN architectures were evaluated for this task: ResNet (ResNet-50 and ResNet-101),[15] DenseNet (DenseNet-121 and DenseNet-169),[16] and EfficientNet (EfficientNet-B0 and EfficientNet-B2),[17] were used for end-to-end age group classification. Age groups were labelled as 0 for individuals under 18 years and 1 for individuals 18 years or older. Training included data augmentation (random rotation, horizontal flipping, zooming and translation), with cross-entropy loss and the ADAM optimiser. Training parameters were initial learning rate 0.00005, weight decay 0.0001, 100 epochs, and batch size of six. In forensic age estimation, avoiding misclassification of minors as adults is critical.[18] Thus, precision was prioritised. The best model was selected based on the highest precision score on the validation set.

Human-defined feature extraction approach

This approach used the same deep learning models and training parameters as the end-to-end method. Data augmentation techniques, the loss function, and the optimiser were similarly applied. However, in contrast to direct age classification, these models were trained to predict the developmental stage of the mandibular third molar. In this approach, labels were assigned based on human evaluation: 0 for "pre-H stages" and 1 for "Stage H." Unlike the end-to-end method, the models' primary objective was accurate classification of mandibular third molar developmental stages. The predicted stage was subsequently used to determine age group, with Stage H indicating individuals 18 years or older, and pre-H stages indicating individuals under 18 years. Model selection on the validation set was based on the highest F1-score. An overview of the age classification approaches is presented in Figure 3.

Experimental setup

The deep learning–based models were developed using Python 3.8.10, PyTorch 1.12.0 and MONAI 0.10.dev2229 with CUDA 11.7 and CuDNN 8.6.0. All experiments were performed on a workstation equipped with a 4-core processor, with 16 GB of RAM and an NVIDIA RTX 2080 8GB graphics card.

Performance evaluation

The models estimated age groups at the 18-year threshold on the test set. Predictions were classified as true positives (TP) for correctly identified individuals older than 18 years, true negatives (TN) for those correctly identified as younger than 18 years, false positives (FP) for individuals under 18 incorrectly predicted as older and false negatives (FN) for those over 18 incorrectly predicted as younger.

These matrices were used to calculate the performance matrices of the validation and testing procedures in terms of accuracy, sensitivity, specificity, precision, and F1-score. These metrics were calculated as follows (Equations 1–5):

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$\text{Sensitivity} = \frac{TP}{TP + FN}$$

$$\text{Specificity} = \frac{TN}{TN + FP}$$

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{F1-score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

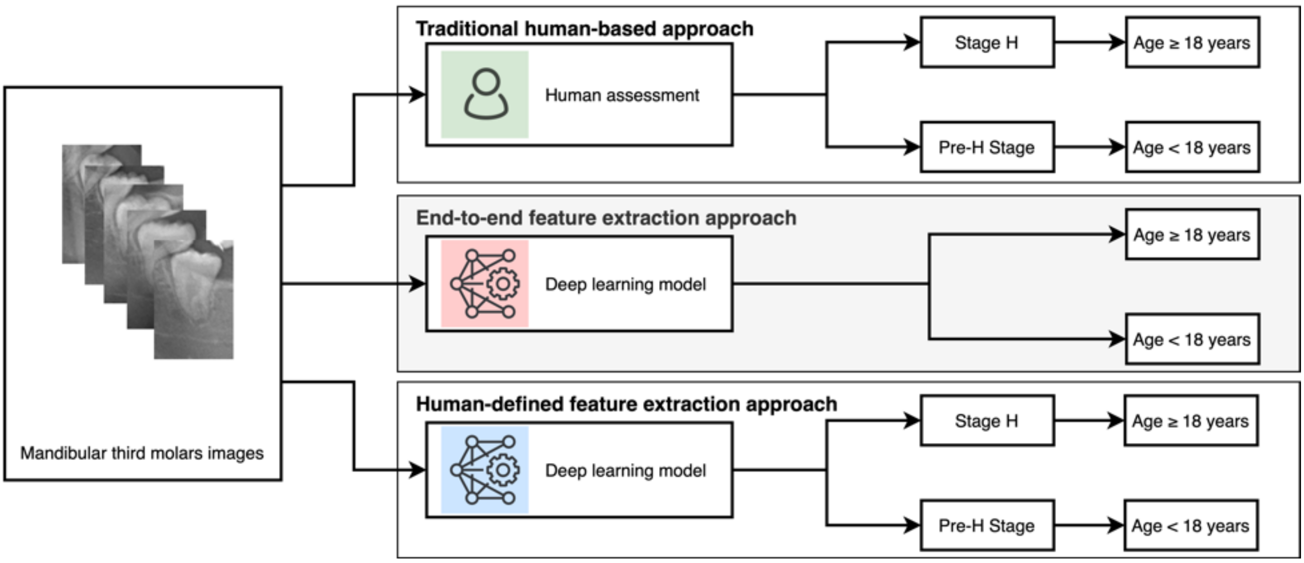
We also calculated the Bayes' post-test probability. This measures the likelihood of a condition after testing, considering pre-test probability and test performance. In legal age classification, a high Bayes' post-test probability ensures reliable predictions for individuals being 18 years or older, which is crucial for legal accuracy.[19] Minimising false positives is essential to avoid wrongful adult classification, ensuring correct legal responsibilities and protections. The calculation of Bayes' post-test probability is as follows (Equation 6):

$$\text{Bayes' post-test probability} = \frac{\text{Sensitivity} \times p0}{\text{Sensitivity} \times p0 + (1-\text{Specificity})(1-p0)}$$

When calculating the Bayes post-test probability, p0 represents the likelihood that an individual belongs to the age range of 18 to 23 years, given that their age falls between 14 and 23 years. To determine this probability, we computed p0 by assessing the proportion of individuals aged 18 to 23 years among those within the 14 to 23 years age bracket in the Thai population. Our investigation, based on data sourced from the Thai National Statistical Office (http://statbbi.nso.go.th), unveiled that the calculated p0 for this specific demographic subgroup stands at 0.61.

In the human-defined feature extraction approach, models classified individuals into developmental stages. True positives were those correctly identified as Stage H, true negatives as pre-H stages, false positives as pre-H stages misclassified as Stage H, and false negatives as Stage H misclassified as pre-H stages. Performance metrics were calculated using the same criteria as before.

Figure 3. Overview of different approaches to age classification including traditional human-based approach, end-to-end deep learning models, and human-defined feature extraction approaches



RESULTS

The results of all approaches to classify age groups at the 18-year threshold are shown in Table 2. The traditional human-based approach achieved a specificity score of 0.99, indicating that nearly all individuals identified as 18 years or older were correctly classified. However, the sensitivity was low at 0.45, indicating that only 45% of individuals aged 18 or older were correctly identified as adults, and the remaining 55% were misclassified as minors. Considering Bayes' post-test probability, this method achieved a value of 0.99, indicating a high probability that individuals predicted to be 18 years or older are so.

The end-to-end deep learning approach, an AI-based method with a straightforward idea, achieved higher scores in accuracy and F1-score than the traditional method. This indicates that this approach can successfully classify individuals as younger or older than 18 years. Among all models, DenseNet-121 achieved the highest accuracy score and F1-score of 0.85 and 0.82, respectively. However, considering the legal context where false positives are the most serious cases to avoid, we further examined the precision score, which represents the accuracy of positive predictions. Although this approach showed improved balance, its lower precision (0.87–0.91) resulted in a higher risk of misclassifying minors, as reflected in slightly reduced Bayes' post-test probabilities (0.93–0.95) relative to the traditional method.

Table 2. Number of mandibular third molar images in the training, validation, and test set

Approach	Model	Accuracy	Sensitivity	Specificity	Precision	F1-score	p
Traditional		0.75	0.45	0.99	0.98	0.62	0.99
End-to-end feature extraction	EfficientNet-B0	0.84	0.72	0.93	0.89	0.80	0.94
	EfficientNet-B2	0.79	0.62	0.92	0.87	0.73	0.93
	DenseNet-121	0.85	0.76	0.92	0.89	0.82	0.94
	DenseNet-169	0.83	0.74	0.91	0.88	0.80	0.93
	ResNet-50	0.83	0.69	0.95	0.91	0.79	0.95
	ResNet-101	0.80	0.65	0.92	0.87	0.74	0.93
Human-defined feature extraction	EfficientNet-B0	0.76	0.51	0.97	0.93	0.66	0.96
	EfficientNet-B2	0.77	0.56	0.96	0.91	0.69	0.95
	DenseNet-121	0.76	0.53	0.95	0.90	0.67	0.95
	DenseNet-169	0.78	0.55	0.97	0.93	0.69	0.96
	ResNet-50	0.77	0.53	0.97	0.93	0.68	0.96
	ResNet-101	0.76	0.51	0.97	0.94	0.66	0.97

p: Bayes post-test probability

The performance of the human-defined feature extraction approach in classifying dental development stages (pre-H stages vs Stage H) is shown in Table 3. The accuracy scores for this task ranged from 0.88 to 0.92 among all models, with DenseNet-169 and ResNet-101 achieving the highest accuracy at 0.92. However, considering the F1-score, which represents the balance of false positives and false negatives, DenseNet-169 outperformed the other models with an F1-score of 0.84. When applying the classified developmental stages from the deep learning model for classifying age groups at the 18-year threshold, all models achieved precision scores ranging from 0.91 to 0.94, with the ResNet-101 model performing the best in this metric. Considering a Bayes' post-test probability, ResNet-101, the best model in this approach, achieved the probability score of 0.97. Although this score was still lower than that of the traditional approach, it was higher than those in the end-to-end feature extraction approach. The results of all approaches to classify age groups at the 18-year threshold are shown in Table 2. The traditional human-based approach achieved a specificity score of 0.99, indicating that nearly all individuals identified as 18 years or older were correctly classified. However, the sensitivity was low at 0.45, indicating that only 45% of individuals aged 18 or older were correctly identified as adults, and the remaining 55% were misclassified as minors. Considering Bayes' post-test probability, this method achieved a value of 0.99, indicating a high probability that individuals predicted to be 18 years or older are so.

The end-to-end deep learning approach, an AI-based method with a straightforward idea, achieved higher scores in accuracy and F1-score than the traditional method. This indicates that this approach can successfully classify individuals as younger or older than 18 years. Among all models, DenseNet-121 achieved the highest accuracy score and F1-score of 0.85 and 0.82, respectively. However, considering the legal context where false positives are the most serious cases to avoid, we further examined the precision score, which represents the accuracy of positive predictions. Although this approach showed improved balance, its lower precision (0.87–0.91) resulted in a higher risk of misclassifying minors, as reflected in slightly reduced Bayes' post-test probabilities (0.93–0.95) relative to the traditional method.

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Table 3. Performance of deep learning models in classifying developmental stages at the Stage H threshold on the test set

Model	Accuracy	Sensitivity	Specificity	Precision	F1-score
EfficientNet-B0	0.91	0.87	0.92	0.73	0.79
EfficientNet-B2	0.88	0.88	0.88	0.67	0.76
DenseNet-121	0.90	0.91	0.90	0.71	0.80
DenseNet-169	0.92	0.95	0.92	0.75	0.84
ResNet-50	0.91	0.92	0.91	0.74	0.82
ResNet-101	0.92	0.91	0.93	0.77	0.83

DISCUSSION

Accurate age estimation is greatly significant in legal and forensic contexts, including criminal proceedings, immigration processes, human trafficking concerns, and the age-specific rights and responsibilities of individuals.[20] However, to date, the only existing study in deep learning-based dental age estimation in Thai populations from panoramic radiographs has shown wide prediction errors of up to five years.[21] Given the 18-year legal threshold, using specific cut-off points for age groups may provide more precise results. In recent years, AI has been increasingly applied in forensic odontology, particularly for age and sex estimation from maxillofacial radiographs.[22] Despite its potential, real-world implementation remains challenging due to the limited transparency and interpretability of AI models. This is especially critical in forensic contexts, where explainability is essential for clinical acceptance and legal defensibility.[23] To address these challenges, we compared the performance of traditional, end-to-end deep learning, and human-defined feature extraction approaches for age classification using mandibular third molars in a Thai population. The inclusion of a stage-based model aimed to enhance interpretability while maintaining high precision, reflecting the need for AI systems that are not only accurate but also aligned with established forensic reasoning. Our results demonstrate notable differences in performance metrics across these methods, highlighting the strengths and weaknesses of each approach in the context of legal age classification.

A recent systematic review demonstrated that AI methods for dental age estimation range from expert-guided approaches to fully automated deep learning models, targeting both numerical and categorical age prediction, including legal age thresholds.[8] Han et al. compared human-based, stage-based, and end-to-end deep learning methods for dental age estimation, finding that the end-to-end model performed best with a mean absolute error of 0.83 years.[24] Similarly, Guo et al. reported superior performance of deep learning over manual methods in classifying ages at 14-, 16- and 18-year thresholds.[25] However, at the 18-year cutoff, deep learning showed lower specificity than Demirjian-based staging, suggesting that end-to-end models may not always be optimal for threshold-based classification tasks.

In forensic contexts, where precise age classification is crucial to avoid misclassifying minors as adults, the precision of these methods becomes particularly significant.[18] Our study aimed to develop a deep learning model optimised for precision to minimise false adult classifications. The traditional method demonstrated excellent precision (0.98) and Bayes' post-test probability (0.99), effectively ruling out false positives but with low sensitivity (0.45), potentially missing some minors. Although the end-to-end deep learning model achieved higher accuracy and F1-scores, its lower precision (0.87–0.91) and post-test probability (0.93–0.95) reduce its reliability in forensic screening. In contrast, the human-defined feature extraction approach balanced performance and interpretability, with improved precision (up to 0.94) and post-test probability (0.97), aided by staging indicators such as Stage H. This approach complements the other methods by enhancing precision and clinical transparency, reflecting the common trade-off between sensitivity and specificity.[26]

To understand the areas of an image that are most important for a model's classification decision, we employed the gradient-weighted class activation mapping (Grad-CAM) technique[27] and analysed the heatmap images of a test group. The area with the greatest influence on the classification was marked in red, whereas the area with the least influence was mapped in blue. Green and yellow represented other portions of the intermediate region. Figure 4 illustrates examples of Grad-CAM of successfully classified age-group cases from the ResNet-50 model, which achieved the highest precision scores in the end-to-end approach. The Grad-CAM revealed that for the under-18 age group, the model highly focuses on the apical structure of the tooth. However, for the over-18 age group, the model's attention is more heterogeneous, with some focusing on the apical region while others pay attention to the mid-root or periodontal ligament space at the cervical region, which is not reasonably understandable by human knowledge. These findings align with a previous study by Gou et al., suggesting that the end-to-end deep learning model might extract more complex and comprehensive features to effectively classify age groups.[25]

Figure 4. Grad-CAM visualisations of successfully classified age-group cases from the ResNet-50 model, which achieved the highest precision scores in the end-to-end approach

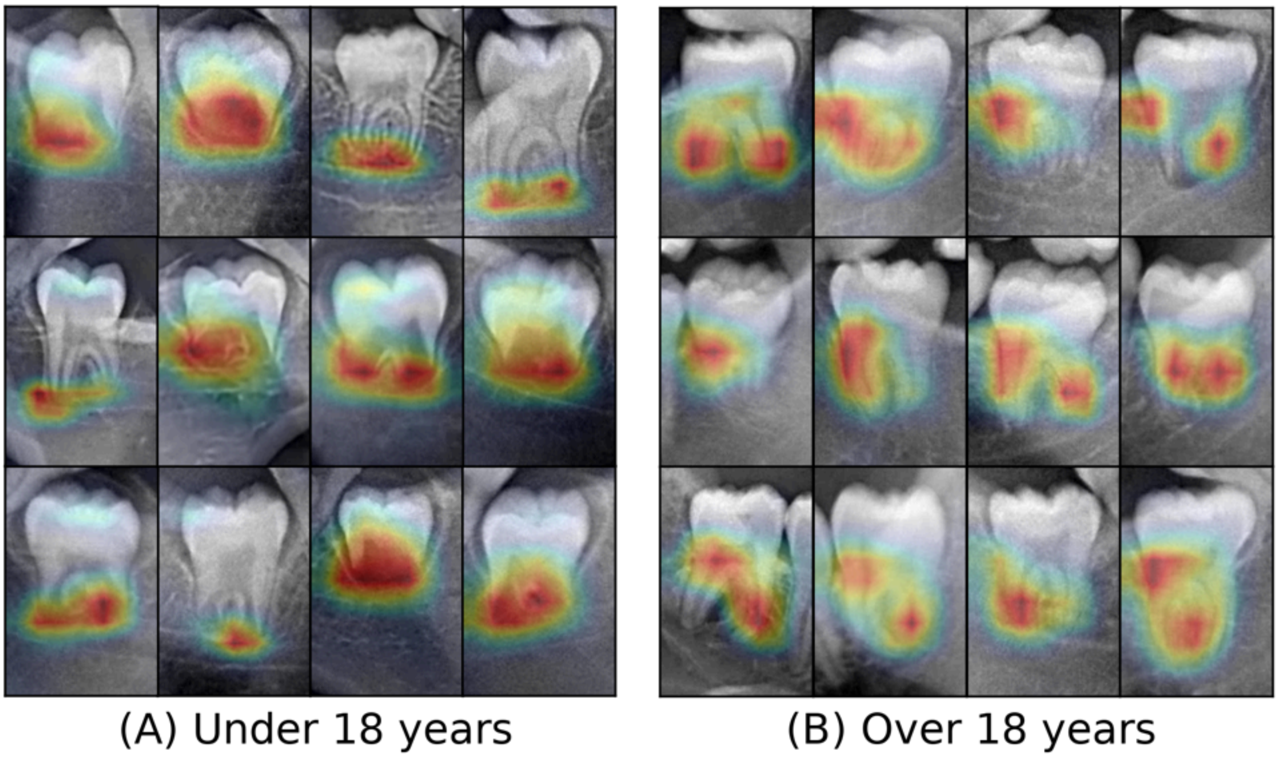
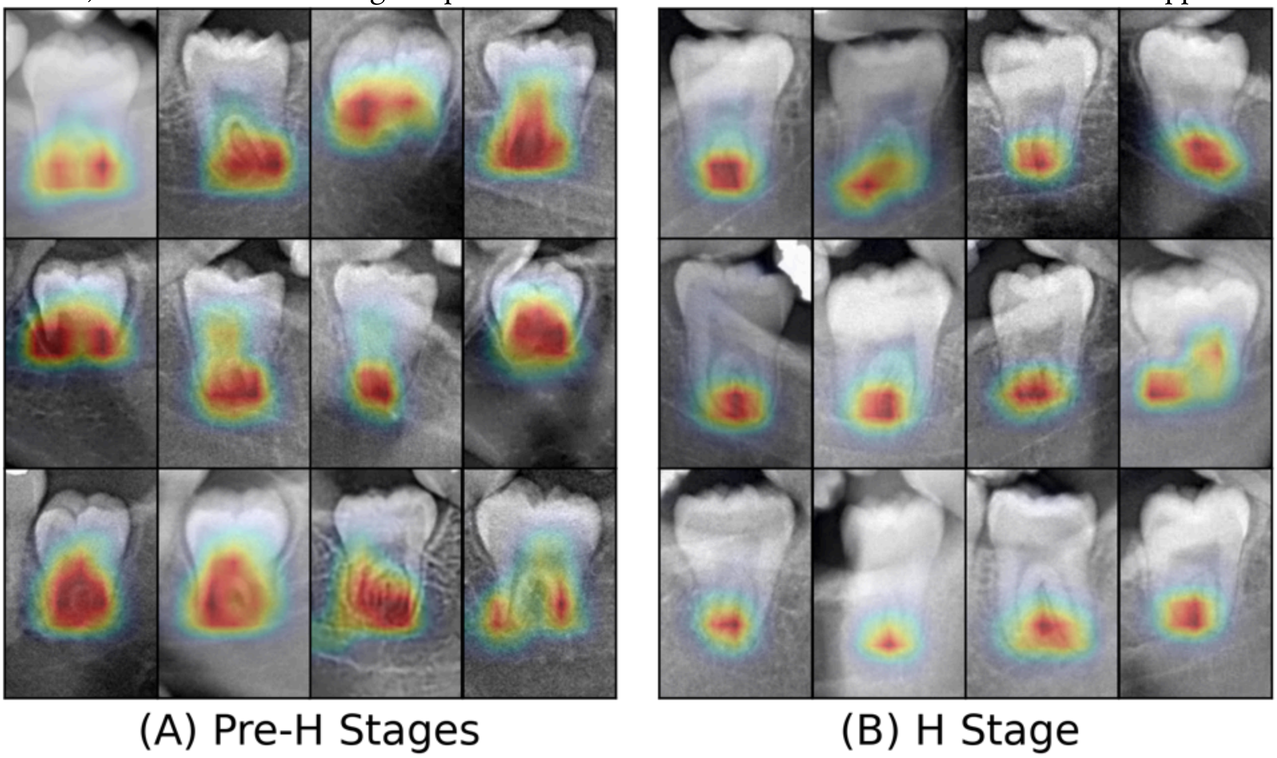


Figure 5 conversely illustrates examples of Grad-CAM of correctly classified age-group cases from the ResNet-101 model, which achieved the highest precision scores in the human-defined feature extraction approach. In both correctly classifying the pre-H stages and the Stage H, the model focused on the apex of the root, aligning with Demirjian's dental development classification concept that emphasises root development. These results suggested that the human-defined feature extraction approach offered more interpretable results that align with established dental development knowledge.

This study has certain limitations. First is its generalisation. Ethnicity plays a crucial role in wisdom tooth mineralisation.[28] A meta-analysis reported that using the fully mature third molar to predict adulthood at the 18-year threshold yields an overall diagnostic accuracy of 71%.[29] In this study, the Demirjian method for age group prediction in the Thai population yielded an accuracy of 86.5%. Variations in accuracy may be caused by genetic diversity among ethnic groups, which affects dental development. These findings emphasise the need to use a population-specific method to estimate the dental age. Therefore, the results of this study should be interpreted cautiously since the analysis was based solely on data from a Thai population and may not be generalisable to other populations. To address this limitation, future studies should validate the model across various ethnic groups to ensure its accuracy and reliability for different populations. This will enhance the model's applicability and effectiveness in universally estimating dental age.

Figure 5. Grad-CAM visualisations of successfully classified age-group cases from the ResNet-101 model, which achieved the highest precision scores in the human-defined feature extraction approach



Data imbalance is a key limitation, especially in developmental stages. Although the age groups were fairly balanced (53.25% under 18 years), pre-H stages dominated the dataset (76.47%) compared to Stage H (23.53%). This imbalance may bias the model against accurately classifying Stage H.[30] Synthetic data, such as that generated by generative adversarial networks in brain tumour classification to improve balance and accuracy,[31] could be a solution. However, no evidence supports this approach in dental radiographs, making it currently unfeasible. Collecting more real data to balance the stages remains the most viable option to improve model performance and reliable classification of Stage H.

Although this study introduced deep learning-based methods for accurate age group classification, the process remained semi-automatic, requiring manual tooth segmentation. Establishing automated detection and segmentation of the tooth of interest is essential for achieving full automation. However, legal and ethical concerns must be addressed. In forensic cases, misclassifying minors can have serious consequences. Human oversight remains essential to ensure that AI predictions are carefully interpreted, with AI serving to support rather than replace expert judgment in sensitive contexts.

CONCLUSION

The traditional method minimised false positives with high precision and strong post-test probability but had lower sensitivity. The end-to-end deep learning model achieved higher accuracy and F1-scores but lower precision, reducing its effectiveness in critical forensic contexts. The human-defined feature extraction approach offered a balanced performance with improved precision and interpretability, making it a useful adjunct for clinicians. However, clinical expertise remains essential to ensure accurate and responsible age classification.

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Assessing the impact of structured teaching on dental age estimation using the Demirjian staging system among undergraduate dental students

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KEYWORDS

Dental age estimation, Dental education, Forensic Odontology, Demirjian Method

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ABSTRACT

Background: Training in dental age estimation (DAE) is inconsistent in undergraduate dental curricula. This study aimed to assess the impact of a structured teaching intervention on the inter-rater agreement and accuracy of undergraduate students using the Demirjian staging method.

Material and Methods: Eighteen dental students with no prior training in forensic odontology assessed seven panoramic radiographs using Demirjian's method during a pre-teaching session. This was followed by a 90-minute lecture led by a qualified forensic odontologist, which included a presentation, interactive discussion, and practical demonstration of the Demirjian staging system. The same radiographs were re-evaluated by the students two weeks later. Inter-observer agreement was assessed using Fleiss' Kappa, while accuracy was determined by comparing the students' staging results to those of the primary observer.

Results: Initial inter-observer agreement was moderate (κ = 0.45), increasing to substantial agreement (κ = 0.76) after the teaching session. Overall, accuracy improved from 46% to 73% post-teaching. The highest improvement was seen in the incisors, which improved from 48% to 92%.

Conclusion: A brief, structured teaching session substantially improved dental students' reliability and accuracy in DAE. Integrating targeted forensic odontology education into the undergraduate dental curriculum is essential, as even brief instructional interventions can yield notable improvements in both staging consistency and accuracy.

INTRODUCTION

Dental age estimation (DAE) is a fundamental component of forensic odontology (FO), involving the assessment of an individual's chronological age through the analysis of age-related changes in the dentition. DAE is an essential tool in legal and migration contexts.[1] For example, when unaccompanied minors seek asylum without reliable documentation, authorities often rely on DAE to verify age.[2] Similarly, DAE is routinely applied in investigations involving suspected juvenile pornography as well as in the identification of unknown juvenile skeletal remains.[3, 4]

For children and adolescents, most DAE techniques are non-invasive and rely on radiological assessment, making them suitable for both antemortem and postmortem examinations.

These techniques evaluate tooth development, which is less affected by external factors than the morphological changes commonly used in adults. [5] Numerous teeth development-based DAE methodologies have been proposed, including atlas-based references,[6] staging systems,[7] and metric measurements.[8]

Among these approaches, staging systems have been widely used.[9] A staging-based DAE assessment generally involves two sequential steps: (1) assigning a developmental stage to one or more teeth and (2) converting that stage into an estimated chronological age. While the second step requires a robust statistical modelling,[10] the first can be susceptible to observer subjectivity,[11] creating the need for systematic training to ensure consistent results.

Recent work by Al Ghazi et al. (2024) highlights the importance of standardised training for forensic odontologists and supports the incorporation of DAE into dental curricula.[12] In line with this finding, the latest revision of Indonesia's National Dental Curriculum mandates that graduating dentists should be able to demonstrate basic competence in FO, including on DAE.[13] This policy is partly driven by the country's geographic vulnerability to natural disasters, which often necessitate large-scale Disaster Victim Identification (DVI) efforts.[14] Therefore, enhancing DAE skills among general dentists is expected to streamline victim identification and professional dental identification efforts across Indonesia. However, meeting these new curricular requirements presents a pedagogical challenge: selecting an appropriate staging methodology and delivering it effectively within the constraints of undergraduate dental education.

The primary objective of teaching DAE staging is to ensure that the students perform the two-step staging process, previously described, consistently and reproducibly. Demirjian method has been widely applied for over five decades,[15] and although several studies have evaluated the reliability of the Demirjian system among experienced practitioners in Europe,[16, 17] Asia,[18] and Africa,[19] its educational impact on inexperienced undergraduate observers remains largely underexplored. Accordingly, this study aimed to evaluate the difference in staging agreement and performance among undergraduate dental students before and after receiving structured teaching and instructions in the Demirjian staging system using panoramic radiographs (PAN).[15] This study was conducted as a pilot study to gather preliminary data on the effectiveness of targeted teaching intervention.

MATERIALS AND METHOD

Participants

A total of 18 undergraduate students participated in the study. Each student was presented with seven PANs, which they were tasked with evaluating the seven primary teeth in the third quadrant using Demirjian's staging system namely FDI 31 to FDI 37. [15]

Samples

The PANs were selected according to the following criteria: healthy children aged between 3 and 10 years, with accessible parental or caregiver contact information to retrieve the child's medical history if needed, and both date of birth and date of radiograph exposure clearly documented. The PAN were retrieved from the archived medical records of patients who attended Universitas Mahasaraswati Educational Dental Hospital, Denpasar, between January and February 2025. Patient anonymity was strictly maintained; students received only the images without any accompanying metadata (e.g., name, sex, date of birth, or date of exposure). None of the PANs were taken specifically for this research.

Children presenting with systemic diseases, genetic disorders, localized oral pathologies, severe malocclusion, or a history of orthodontic treatment were excluded from the study. All datasets were collected by the first author.

Students were eligible as participants if they had successfully completed and passed the Anatomy and Radiology module with a minimum grade of 65 and had not yet commenced the FO module. Students who were absent or did not fully attend the DAE course were excluded from the study. This study was conducted as part of a class-based evaluation for internal educational purposes and involved no to minimal risk, ethical clearance was given by the local ethical committee Number: K.541/A.17.01/FKG-Unmas/V/2025. All participants were informed about the purpose of the study and provided written consent prior to participation.

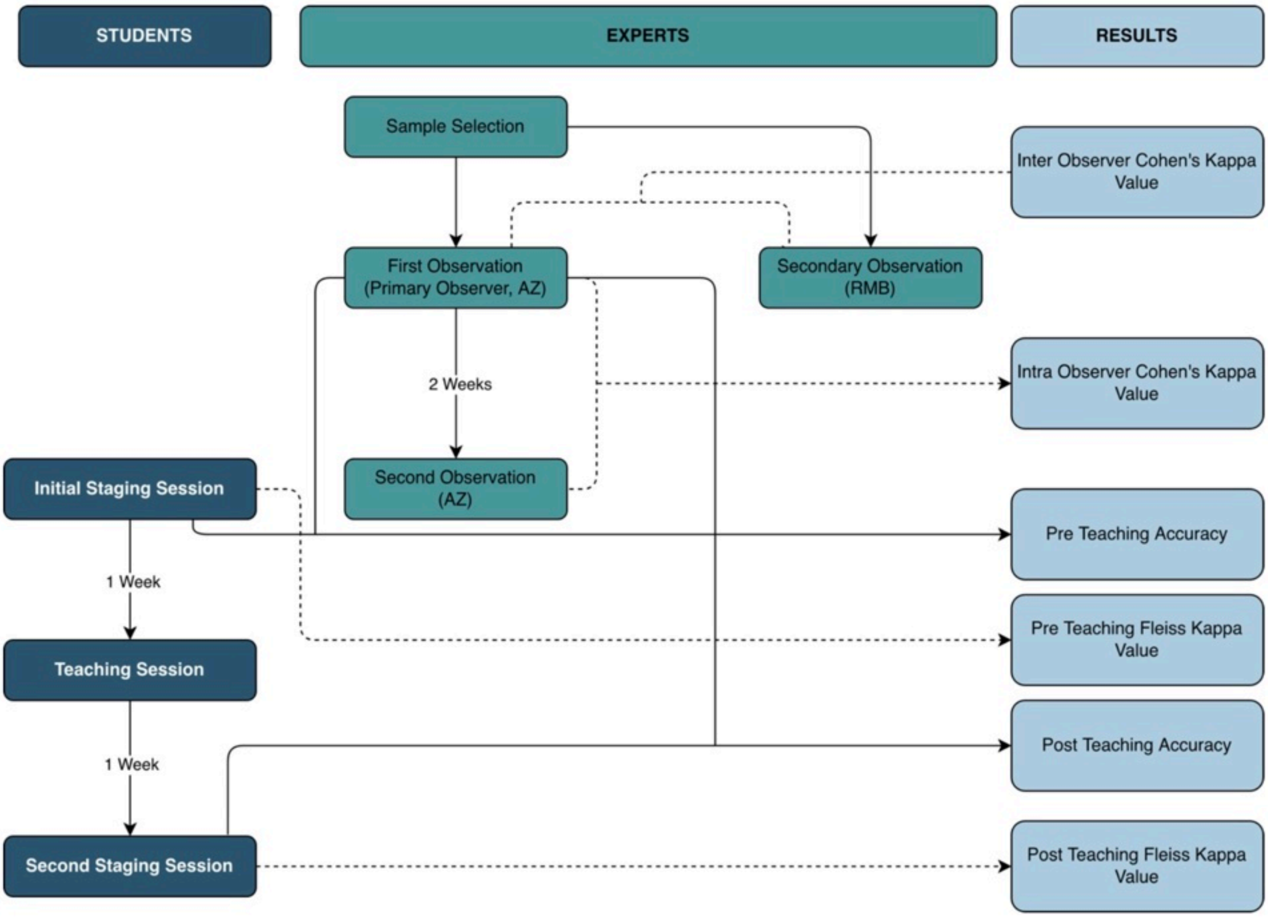
Rationale behind the selection of the staging system

Several tooth staging techniques exist in DAE, including Nolla's foundational work on the development of permanent teeth in 1960,[7] followed by the standards for tooth formation and emergence developed by Moorrees et al., in 1963.[20] Even so, the Demirjian system was chosen for this research as it is one of the most popular staging systems used [15] and it has been used as the staging approach not only to estimate age according to original Demirjian's study, but also in subsequent research that considered the developmental stages to propose new individual dental age scores.[21,22] Additionally, the Demirjian method has fewer developmental stages when compared to other staging systems,[9] which may facilitate easier learning and application. [23,24]

Teaching session and evaluation

The full timeline of the current research is illustrated in Fig. 1. The staging process was conducted in two separate sessions: one before and one after a dedicated DAE lecture session. The initial staging session (Pre-teaching) occurred prior to any formal DAE instruction; students were only provided with the original Demirjian publication via email, and the corresponding staging diagrams were displayed on-screen during the session. The second session took place two weeks later, following the teaching intervention.

Figure 1. Timeline between observation and teaching for the Primary Observers and Students



The lecture sessions were delivered by the primary author (APZ), a forensic odontologist with four years of professional experience, through three separate 90-minute lectures. Each session included a presentation, discussion, and a live demonstration of the Demirjian staging system.[15] Each of the stages (i.e., Stage A, B) was thoroughly examined and explained in detail to enhance students' understanding, until consensus was achieved. Additionally, participants were provided with a standardised calibration guide. For example: (1) when there is an uncertainty regarding which stage to choose, or a tooth fell between two stages, the students were instructed to select the lower stage, (2) when a tooth has two different stages, especially in multi-rooted teeth (i.e., distal root of FDI 36 was at stage G and the mesial root was at stage H), the lower stage was taken into consideration, and (3) students were allowed to use any image processing software to aid with the staging process, but only limited to adjusting contrast and brightness based on their own preferences. After the session, students were provided with the same seven PANs for which they were asked to complete the staging in a newly randomized order. All observers were blinded to all PANs metadata during all evaluation periods.

Data analysis

Three distinct types of agreement were assessed in this study: Primary observer, pre-teaching, and post-teaching agreement. First, the intra- and inter-rater agreement of the primary observer (APZ) was assessed using Weighted Cohen's Kappa. The intra-rater agreement was calculated based on two observations taken two weeks apart, and the inter-rater agreement was calculated by comparing the initial measurements of the primary observer to those of a second observer (RMB), a forensic odontologist with eight years of experience in DAE research and clinical practice.

Second, the pre-teaching agreement was assessed in intra-rater reliability using Fleiss' Kappa between the students. Lastly, the resulting kappa values were compared to evaluate the improvement in agreement in the post-teaching session. An additional evaluation of staging accuracy was conducted by calculating the average number of correct answers per session, as determined by comparison to the primary observer. To determine the precision of these estimates, 95% confidence intervals (CI) for both Kappa and Accuracy measures were generated using the bootstrapping method with 2000 replications with set.seed of 33. All statistical analysis were performed using RStudio version 4.3.1 with irr and boot packages.

RESULTS

A total of 49 teeth from seven PANs were evaluated by 18 students. The primary observer intra-rater agreement Kappa was 0.95 [95% CI 0.88-1], and the intra-observer agreement Kappa was 0.7 [95%CI 0.55 – 0.85].

The overall result of the Fleiss' Kappa Agreement was reported in Table 1. In the initial staging session, the students' overall inter-observer reliability was 0.45 (95%CI 0.42 – 0.5). An improvement in inter-observer reliability was observed in the post-teaching staging session, with the Fleiss' Kappa value improved to 0.76 (95%CI 0.69 – 0.84).

In terms of tooth regions (i.e., Anterior and Posterior), the highest improvement of staging agreement was observed in the anterior region (Δk = +0.38) compared to the posterior region (Δk = +0.34). Regarding the tooth type (i.e., Incisors, Canine, Premolars, Molars), the lowest inter-observer agreement was in Incisors (k = 0.13), and the highest inter-observer agreement was in Molars (k = 0.53). In terms of improvement, the highest improvement was observed in Incisors (Δk = +0.73) and the lowest improvement was in Canine (Δk = +0.11). In each FDI tooth (i.e., FDI 31, FDI 32), the lowest improvement was in FDI 33 (Δk = +0.11), and the highest improvement was in FDI 31 (Δk = +0.55).

The overall accuracy was reported in Table 1. The initial accuracy of the students was 0.46 (95% CI 0.43 – 0.5) which then later improved to 0.73 (95% CI 0.7 – 0.77) after the teaching session. Similar to the kappa improvement, the tooth region accuracy improvement was observed in the anterior tooth (ΔAcc = +0.37). Regarding the tooth type, the highest improvement was also observed in the Incisors (ΔAcc = +0.44), and the lowest improvement was in the premolar region (ΔAcc = +0.07). In each FDI tooth, the highest improvement of accuracy was observed in FDI 37 (ΔAcc = +0.42), and the lowest improvement of accuracy was in FDI 34 (ΔAcc = +0.01).

DISCUSSION

The current study observed an overall improvement, both in terms of observer agreement and accuracy among undergraduate dental students using the Demirjian staging method.[15] These findings demonstrate a clear improvement following the educational intervention delivered by a trained forensic odontologist, supporting the hypothesis that formal instruction, demonstration, and calibration improve students' ability to perform dental staging reliably.

Table 1. Student's Fleiss Kappa and Accuracy in using Demirjian Staging.

Observations	Fleiss' Kappa (95% CI)		Accuracy (95% CI)	
	Pre-Teaching	Post-Teaching	Pre-Teaching	Post-Teaching
Overall	0.45 (0.42 – 0.5)	0.76 (0.69 – 0.84)	0.46 (0.43 – 0.5)	0.73 (0.7 – 0.77)
Tooth Regions				
Anterior	0.43 (0.28 – 0.57)	0.81 (0.5 – 1)	0.45 (0.37 – 0.47)	0.82 (0.77 – 0.85)
Posterior	0.4 (0.11 – 0.49)	0.74 (0.41 – 1)	0.5 (0.45 – 0.54)	0.67 (0.63 – 0.71)
Tooth Type				
Incisors	0.13 (0.04 – 0.24)	0.86 (0.29 – 1)	0.48 (0.44 – 0.56)	0.92 (0.87 – 0.94)
Canine	0.42 (0.26 – 0.59)	0.53 (0.27 – 0.8)	0.25 (0.17 – 0.32)	0.62 (0.54 – 0.71)
Premolars	0.38 (0.28 – 0.47)	0.76 (0.61 – 0.93)	0.45 (0.43 – 0.55)	0.52 (0.45 – 0.57)
Molars	0.53 (0.38 – 0.66)	0.78 (0.41 – 1)	0.52 (0.43 – 0.56)	0.81 (0.78 – 0.88)
Tooth FDI				
31	0.23 (-0.01 – 0.39)	0.78 (0.33 – 1)	0.6 (0.52 – 0.69)	0.92 (0.86 – 0.95)
32	0.28 (0.06 – 0.43)	0.8 (0.38 – 1)	0.41 (033 – 0.49)	0.91 (0.85 – 0.95)
33	0.42 (0.26 – 0.59)	0.53 (0.27 – 0.8)	0.25 (0.17 – 0.33)	0.62 (0.54 – 0.7)
34	0.34 (0.18 – 0.43)	0.58 (0.4 – 0.83)	0.54 (0.45 – 0.62)	0.55 (0.46 – 0.63)
35	0.35 (0.18 – 0.5)	0.59 (0.41 – 0.78)	0.44 (0.35 – 0.52)	0.48 (0.39 – 0.56)
36	0.14 (0.03 – 0.3)	0.58 (0.26 – 1)	0.45 (0.36 – 0.53)	0.69 (0.61 – 0.78)
37	0.37 (0.11 – 0.55)	0.9 (0.6 – 1)	0.55 (0.45 – 0.73)	0.97 (0.9 – 0.98)

Tooth Numbering Follows Federation Dentaire International (FDI) Tooth Numbering. CI = Confidence Interval

The increase in Fleiss' Kappa from 0.45 to 0.76 post-teaching reflects a substantial improvement in inter-rater agreement among the students, shifting from moderate to substantial agreement according to Landis and Koch's benchmark scale.[25] This suggests that even a brief, structured teaching session, when supported by interactive review and group discussion, can substantially improve staging consistency even with inexperienced dental students. However, it should be noted that the students had prior exposure to radiographic assessment in their previous semester, and different results are expected when no previous lessons in oral radiography have been taken by the students.

The results of our study suggest that enhancements in staging consistency and accuracy differed based on the specific parameters examined, which give specific patterns of error among the students. For this context, distinct pairs of observations need to be evaluated carefully. First, a high agreement with low accuracy suggests consistent misinterpretation of developmental stages. For example, in FDI 33 the students' Fleiss' Kappa was 0.42 and the accuracy was 0.25. This pattern of consistent but incorrect staging was also observed at a group level for the molars, which had the highest pre-teaching agreement of any tooth type ($\kappa = 0.53$) yet only achieved a moderate accuracy of 0.52. Secondly, a lower Fleiss' Kappa value paired with a high accuracy may indicate that students are randomly guessing and arriving at the correct answer by chance. This was observed in tooth 31 with 0.23 Kappa and 0.6 accuracy. The pattern was also observed for the incisors group, where a very low agreement ($\kappa = 0.13$) was paired with an accuracy of 0.48. Such variations were markedly reduced following the instructional intervention, as both types of inconsistencies were frequently observed during the pre-teaching sessions.

The undergraduate dental education aims to provide students with a solid foundation to become competent dentists to provide societal needs, in this case, to be proficient in FO with the basic skill in DAE.[26] Although the current focus of the dental staging was to be used as a forensic tool for age identification, DAE can also be useful in other parts of dentistry. For example, assessment of dental growth can influence diagnosis, objectives, treatment planning, and the eventual outcome of orthodontic treatment.[27] Additionally, assessment of dental maturation can detect the peak of pubertal growth spurt.[28] Therefore, the study of DAE not only enhances a dentists' understanding of FO but also has practical applications across various other fields of dentistry. Introducing this knowledge early in dental education can foster professional versatility and may inspire students to pursue FO as a career path.[29]

Despite the importance of teaching DAE, a recent pilot demographic study found that a substantial percentage of respondents — specifically, 50% of active forensic odontologists and FO students worldwide— reported that FO was either not included in their undergraduate education or had been removed from the dental curriculum.[29] Integration of FO into undergraduate curricula often remains limited, resulting in overall lower awareness of the field, especially in developing countries.[30,31] This lack of exposure to FO may contribute to insufficient training in DAE and limited familiarity with forensic procedures, potentially compromising the reliability of forensic assessments in legal, humanitarian, and, most critically, disaster preparedness contexts. In the event of a mass disaster, dentists and dental professionals should be prepared to assist with dental identification.[32] Dental students or recent graduates with specialized training may be deployed in DVI efforts to assist in the collection, organization, and transcription of antemortem and postmortem data. They may also serve in a consultative capacity, supporting forensic odontologists during the comparative analysis phase. Formal training allows general dentists to contribute more effectively to the overall response, thereby reducing challenges related to professional coordination in the field.[33]

A recent example of FO in undergraduate dental education can be found at the European University Cyprus School of Dentistry.[34] Despite being a relatively new dental programme, FO has been successfully integrated into the undergraduate curriculum, where students engage in anthropological analysis and learn to create biological profiles for unidentified individuals. This highlights how early, structured exposure to FO can improve students' skills and better prepare them for their professional careers.

Several limitations must be acknowledged. First, as a pilot study, the primary small sample size (18 students) and limited number of PANs (n = 7) may restrict the generalizability of the findings, and the marked improvements observed may not be fully representative of the broader undergraduate dental student population. Secondly, the short interval between two staging sessions may also introduce recall bias, although the anonymised nature of the images and random sequences of the PANs were designed to minimize this risk. Thirdly, only the mandibular left region —as proposed originally by Demirjian et al., in 1973 — was observed in this study. It has been reported by previous studies that maxillary teeth are harder to stage, even by the experts.[11] Finally, this study lacked a long-term follow-up to assess whether the observed improvement in skill was retained over time. Even so, greater variability in agreement was anticipated among inexperienced observers, such as undergraduate dental students.

Future research should investigate long-term outcomes and assess the impact of various teaching strategies, such as simulations and case-based learning. Additionally, further studies evaluating alternative staging methods that incorporate more developmental stages than the Demirjian system are warranted.[15] Such approaches could help identify the most suitable methodologies for educating undergraduate dental students, with the goal of effectively introducing them to the principles of FO.

CONCLUSION

Structured teaching substantially enhances dental students' inter-rater reliability and accuracy in applying the Demirjian staging method compared to an experienced observer. Given the increasing forensic and legal reliance on DAE, it is crucial to equip dental students with these skills. The integration of targeted FO education into undergraduate dental curriculum is essential, as brief instructional interventions can lead to meaningful improvements in both staging consistency and accuracy, while also potentially inspiring new generations of prospective forensic odontologists.

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A survey on perceptions of denture labelling and marking among dental practitioners in Australia – a pilot study

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ABSTRACT

Background: Denture labelling is an underutilised tool with many applications. Identification of patient's denture can help to prevent loss of the appliance and be used posthumously in Forensic Odontology.

Aim: The aim of the survey was to assess the perceptions, education, and technique preferences of dental practitioners regarding denture labelling in Australia and identify any barriers. The survey also assesses the dental practitioners' awareness of denture labelling and forensic dental identification.

Materials and methods: A questionnaire survey was conducted between "March 2023 to November 2023". Participants consisted of general dentists, prosthodontists and dental prosthetists were surveyed across Australia. Participants who were recruited anonymously via email and information sheet through organisations including the Australian Dental Prosthetist Association (ADPA), Griffith University, the University of Sydney, and the Royal Australasian College of Dental Surgeons. The survey consists of twenty-one questions relating to the participants' demographic background, the practice of denture labelling in their workplace, and awareness of denture labelling and forensic dental identification.

Results: Fifty-two participants completed the survey. Participants include thirty-three general dentists, sixteen dental prosthetists and three prosthodontists. 63.5% (n=51) of the participants were not taught to label dentures. The majority (67.3%; n=35) of the practitioners had never labelled a denture, whereas 15.4% (n=8) labelled dentures less than once a year, and 11.5% (n=6) monthly. Dental prosthetists and Prosthodontists are more likely to label a denture than a general dentist (p=0.003). Removable complete acrylic dentures were most commonly labelled (maxillary 94%; n=16 and mandibular 81%; n=14), with the preference for placing the label posteriorly at the palatal and lingual surfaces of the maxillary and mandibular denture (39%; n=26and 36%; n=25 respectively). The most significant barriers to denture labelling were time (mean score: 2.98 out of 5) and labour (mean score: 2.88 out of 5). The cohort was split on their exposure to forensic odontology (46%; n=24 said yes, 50%; n=26 said no);however, 71% (n=37) were aware that denture labelling could be used for forensic dental identification, and 75% (n=39) in support of mandatory denture labelling in hospitals and aged care facilities.

Conclusion: Denture labelling remains an underutilised in Australia despite widespread recognition of its value. Dental prosthetists and more experienced practitioners were more likely to implement denture labelling; however, time, labour, and cost were identified as key barriers. Although denture labelling is insufficiently covered in dental curricula, practitioners demonstrated awareness of its benefits and expressed strong support for making it mandatory in institutional settings.

INTRODUCTION

Despite the importance of denture labelling, the practice is not routine among dental practitioners. [1, 2] Across Australia, 19% of adults aged 65 and over had no natural teeth. In addition, population above 65 years old with natural teeth, 42% wore dentures. This is predicted to increase as older generations maintain more of their teeth and receive partial dentures. [3, 4] Moreover, Forensic Odontologists can utilise unique markings on dentures to create a circumstantial identification of an unidentified body. [5] Dentures can be labelled on the surface or included in the resin layering. Both methods have advantages and disadvantages; however, there is no recommended internationally recognised approach. Many governing bodies and State Health organisations recognise the importance of denture labelling and recommend its use, however, few stipulate it as a requirement. [6, 7]

Partial and complete dentures play an important role in improving the patient's quality of life, impacting their masticatory function, nutritional intake, aesthetics, phonetics and social engagement. [8, 9] In Australian residential aged care, an estimated 41% of residents wear dentures. [10] As part of their routine hygiene practices, some care facilities collect all the residents' dentures simultaneously and clean them in bulk before returning them, which can lead to dentures misplaced. [11] Dentures are also commonly lost in secondary care facilities such as hospitals when left on meal trays, hidden in bed linens, lost in transit between wards or expelled during an episode of vomiting or seizure. A survey of United Kingdom (UK) hospitals from 2011 to 2016 demonstrated that 695 dentures were lost while patients were receiving in-patient care. [2] A follow-up study from 2016 to 2021 reported 123 dentures were lost during that period with improvements being attributed to nursing staff awareness and denture container labelling. [8, 12]

With 371,000 Australians living in residential aged care and 47% of those aged over 75 years wearing dentures, labelling those dentures would benefit a large proportion of the population. [4, 13] There has already been an increase in denture wearing in older populations from 47% of those aged 65 and over in 2012 to 25% of 55-74 year-olds and 47% of those aged 75 and over in 2017-18. [3, 4] As edentulism declines, more people retain their teeth and are more likely to receive partial dentures. [14, 15] Replacing lost dentures remains complex and resource-intensive. The cost of a full set of upper and lower dentures can range from $2003 to $2504 AUD. [16] For many elderly Australians, this cost or waiting period deters them from seeking much-needed dental care. [2,17] People with disabilities encounter additional barriers to receiving dental treatment including transportation, inaccessible facilities, time, experience of the dental professional and anxiety. [2, 17]

For forensic purposes, labelled dentures can provide a fast, inexpensive, and reliable aid in the circumstantial identification of a deceased person. [18] Alongside fingerprints and DNA, forensic odontology is recognised by INTERPOL as a primary identifier for Disaster Victim Identification (DVI). [19] Identification through dentures has been documented since 1835, when the remains of the Countess of Salisbury were identified via her gold denture. [20] Following World War II, 819 of the 3000 unidentified deceased soldiers wore dentures; however, only 1 in 9 could be identified by their dentures. [21] Forensic odontology is highly regarded when identifying bodies that are incinerated. Prosthodontic devices, particularly metal-based, can withstand higher temperatures, and when well-protected within the tissues, they can be valuable in cases of incineration. [22, 23] Despite the advantages, denture labelling is not regularly performed due to "cost, lack of awareness of standards, and a belief that marking was of little importance" cited by Alexander, Taylor (p. 337). [24]

There are two methods of denture labelling, which are inclusion and surface marking. Surface marking is done after the denture is processed by writing the identifying details on an abraded surface of the denture with an indelible pen. [25]

This method is used infrequently (9%) as it creates a plaque-retentive surface that can be irritating to the tissues and removed over time with routine cleaning. [26] Inclusion remains the preferred method (89%), where either a metallic (stainless steel tape) or paper label is placed in the denture during the packing stage and covered with clear acrylic. [25, 27]

The tape or label is normally placed on the buccal flange or palatal base surface of maxillary dentures or the lingual flange of mandibular dentures. If placed on the fitting surface of the denture, it can interfere with denture relines, potentially impacting fit and comfort. When considering post-mortem identification, withstanding incineration is valuable and metallic labels are ideal for their high melting point. The metal tape material is readily available in many dental laboratories; however, it is considered less aesthetic than a transparent or onion paper label. [28] An additional benefit of metal labels is being radiopaque and therefore detectable in post-mortem computed tomography (PMCT) and radiographs if a temporary partial denture is aspirated. [26]

Regulatory requirements for denture labelling vary by jurisdiction. In the United States of America (USA), 22 states require denture labelling, with inclusion preferred for acrylic appliances and surface marking by laser etch for chrome cobalt dentures. [6] Dentists in Sweden have been mandated by the National Board of Health and Welfare since 1986 to offer denture labelling to patients and to explain its benefits. [7]

There are conflicting reports in the literature regarding how many dentures receive labelling, with Swedish dentists self-reporting 81-100% uptake whilst a screening of dentures in selected nursing homes found that 35% of complete dentures were labelled. [29, 30]

In several countries, denture labelling is recommended however is not regulated. The National Health Service (NHS) Scotland has the "Caring for Smiles" program, promoting that "All dentures should be marked with the resident's name or other form of identity". [31] Surveys of UK prosthodontic specialists indicate that 54.9% routinely label complete dentures and 81% believe it was a worthwhile procedure. [1] Historic screening of complete dentures in the UK indicated that 47% were labelled; however, this study by Bengtsson, Olsson [32] predates the "Caring for Smiles" campaign and there may have been an uptake in denture labelling frequency since then.

In Australia, the Nursing Home Standards of 1987 require that residents' dentures be "discreetly labelled". [33] The ADA Policy Statement 6.16 on Forensics in Dentistry; states that "dentures should be marked with the patient's name and such marking noted in the dental record". [34] The 2024 update of the Australian Government's Aged Care Quality Standards does not specifically mention denture labelling, outlining that clear policies must be available for all carers relating to oral and dental care delivery, inventory management and equipment maintenance. [34, 35]

Alexander, Taylor [24] surveyed dental practitioners in South Australia; 20% of general dentists, 25% of prosthodontists and 43.5% of dental technicians self-reported to occasionally label dentures. Many of the surveyed population were unaware of the Nursing Home Standards or recommendations by the ADA. [24]

Labelling of dentures is a critical procedure for patients receiving treatment in hospitals and care facilities, where dentures are more likely to be lost. [31] In death, labelled dentures can assist forensic odontologists in the identification of unidentified remains. [22] Methods of labelling include surface marking or inclusion with the latter being preferred. Denture labelling is commonly practised in the USA, UK and Sweden. [6, 7] Australia has requirements relating to the labelling of dentures in nursing homes; however, many dental practitioners appear to be unaware of this regulation. [24] The aim of this study was to assess the perceptions, education, and technique preferences of dental practitioners regarding denture labelling in Australia and identify any barriers.

MATERIALS AND METHOD

Ethical approval for the study was granted by Griffith University Human Research Ethics Committee (GUHREC), approval number GU Ref No:2022/771.

The study involved a questionnaire survey (appendix 1), which was conducted between "March 2023 to November 2023". Invited participants consisted of general dentists, prosthodontists and dental prosthetists. Participants were recruited via email and information sheet through organisations including the Australian Dental Prosthetist Association (ADPA), Griffith University, the

University of Sydney, and the Royal Australasian College of Dental Surgeons. The survey was facilitated on the Microsoft Forms software platform (Microsoft, Washington, United States of America); no incentives were offered for survey completion, and as their participation was anonymous, no age or gender demographics data were collected.

The survey consists of three parts and twenty-one questions. Part one's questions were related to demographic background, part two's questions were related to denture labelling or denture marking preferences (see Figure 1, Figure 2 and Figure 3), awareness, education, and perceived barriers, while part three's questions covered denture labelling or denture marking and forensic dental identification, record-keeping, and privacy.

Figure 1. An illustrative example of labelling site on the buccal flange of a complete maxillary denture

Figure 2. An illustrative example of labelling site on the palatal flange of a complete mandibular denture

Figure 3. An illustrative example of labelling site on the lingual flange of a partial mandibular denture (metal base).

Variables analysed included participant demographics, denture labelling practices, knowledge and awareness of denture labelling techniques, its forensic Odontology applications, barriers and support. The survey data were analysed using IBM Statistical Package for Social Sciences (SPSS) (IBM, New York, United States of America) and Microsoft Office Excel (Microsoft, Washington, United States of America), focusing on descriptive statistics, cross-tabulations and inferential statistics to identify relationships between variables. Missing values were excluded from analysis on a per-variable basis. Chi-square test of independence was used to analyse the data.

RESULTS

A total of fifty-two participants completed the survey: thirty-three general dentists, sixteen dental prosthetists and three prosthodontists, represented as percentages in Figure 4.

The average years of experience amongst the participants were between three to five years for general dentists and more than ten years for both prosthodontists and dental prosthetists. There was a significant association between years of experience and frequency of labelling dentures in practice ($p<0.001$). Dental Prosthetists were significantly more likely to perform denture labelling compared to General Dentists ($p = 0.003$). Figure 5 shows the distribution of primary practice locations within Australia, noting the prominent proportion from New South Wales (NSW) and Queensland (QLD); 38.5% (n=20) and 32.7% (n=17) respectively.

Figure 4. Distribution of the fifty-two surveyed dental practitioners by division.

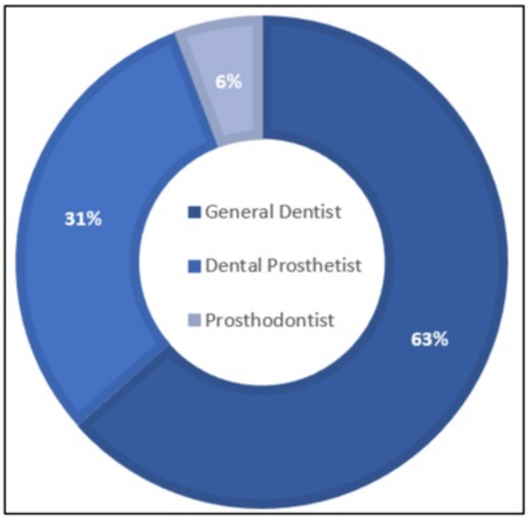
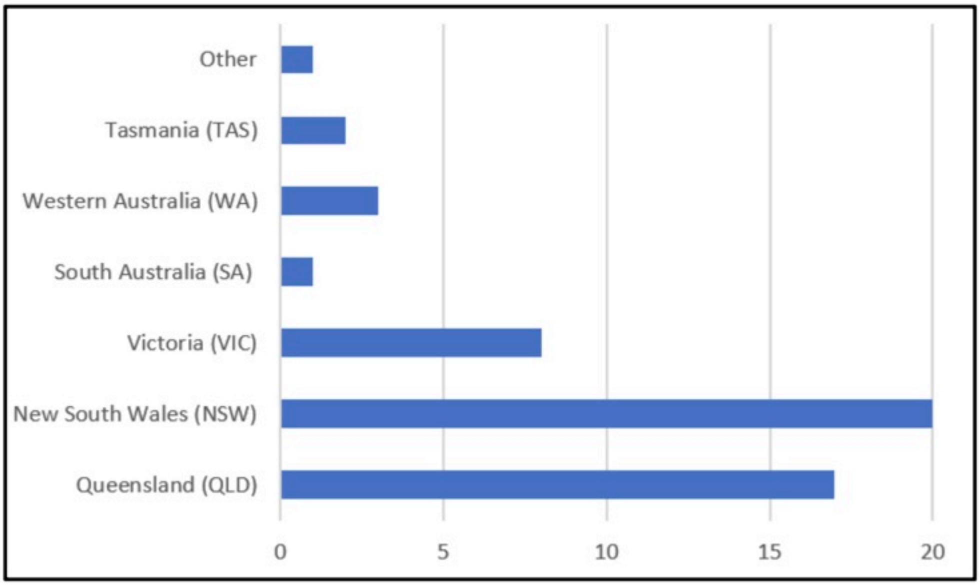


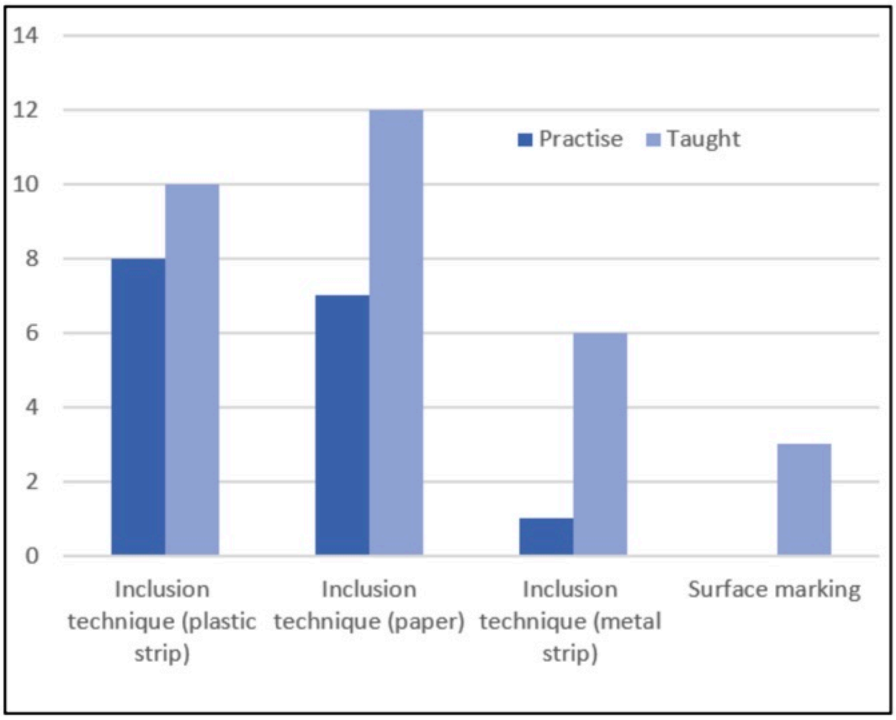
Figure 5. Distribution of the fifty-two dental practitioners by their primary practice location.



The majority (67.3%; n=35) of the practitioners had never labelled a denture; 15.4% (n=8) labelled dentures less than once a year and 11.5% (n=6) monthly. Two of the daily denture labellers were dental prosthetist and the other a prosthodontist. Dental prosthetists and Prosthodontists were more likely to have labelled a denture than a general dentist (p=0.003). Among the 17 practitioners who had labelled dentures, removable complete acrylic dentures were the most frequently labelled (maxillary 94%; n=16; and mandibular 81%; n=14). Removable partial acrylic and metal-based dentures were labelled less often (34% (n=6) and 25% (n=4) respectively). Three respondents also reported labelling mouthguards and implant-supported dentures.

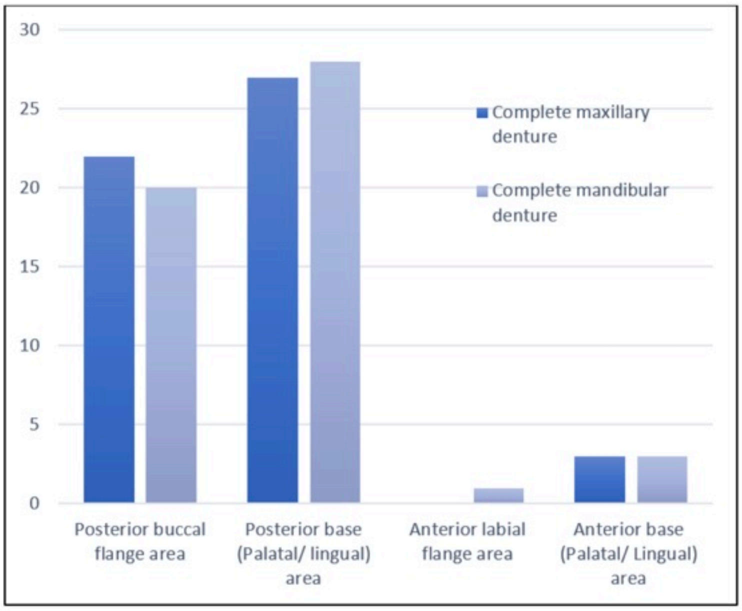
When considering the patient perspective, 61.5% (n=32) of practitioners had never been asked by a patient to label their dentures. Of the sixteen practitioners who had, complete maxillary and mandibular acrylic dentures were most frequently requested (41%; n=7). Figure 6 demonstrates different techniques of denture labelling, comparing against the practitioner's training and what technique they elect to practice presently. A large proportion were not taught to label dentures (63.5%; n=33). Of the practitioners who have labelled dentures, the inclusion technique with plastic and paper was preferred and more routinely taught during their training. The least popular was surface marking, with just three practitioners receiving training and none opting for this technique in their practice.

Figure 6. Clusters column graph comparing denture labelling techniques practiced and taught by the fifty-two surveyed dental practitioners.



Using the patient's first and or last name on the label was the most common approach for identification (66.7%; n=24), initials or name and date of birth (11.1%; n=4 and 8.3%; n=3 respectively) were less favoured. Figure 7 shows that there was a preference for placing the label posteriorly in both the maxillary and mandibular dentures, specifically along the base of the palate and lingual surfaces (48%; n=25 and 50%; n=26 respectively) followed by the buccal flange (39%; n=20and 36%; n=19respectively). More experienced practitioners showed a significant preference for posterior palatal/lingual base areas, while less experienced practitioners preferred buccal flange areas. The majority of practitioners (63%; n=33), stated that they were not aware of the ADA item code (#777) for the 'Marking a dental appliance with a patient's name or other form of enduring patient identification.'

Figure 7. Clustered column graph reviewing the preferred location of label on complete maxillary and mandibular acrylic dentures.



Practitioners reported that their perception of time (mean score: 2.98 out of 5) and labour (mean score: 2.88 out of 5) were the most significant barriers to labelling dentures. Patient privacy and cost were less of a concern. The practitioners do not doubt the usefulness of labelling, with 75% (n=39) in support of mandatory denture labelling in hospitals and aged care facilities.

The cohort was split on their exposure to forensic odontology (46%; n=24 said yes, 50%; n=26 said no and 4%; n=2 were unsure). When exploring this exposure against their division, all of the prosthodontists and half of the general dentists had been exposed during their training, compared to 30% (n=5) of dental prosthetists. Despite the partial exposure, 71% (n=37) were aware that denture labelling could be used to aid in the identification of a deceased person. There was some disagreement regarding recording the details of the label placed on the denture in the patient's dental records with 39% (n=20) saying they do record it, 36% (n=19) are not and 25% (n=13) were unsure. Patients do not appear to consider dental labelling to be a privacy breach, with 84% (n=45) of practitioners confirming that no patient has shared this concern with them. Finally, 75% (n=39) of practitioners would be supportive of denture labelling becoming a mandatory requirement for patients with complete dentures in hospital or aged care facilities.

DISCUSSION

The study reveals that denture labelling is not a common practice among dental practitioners in Australia, with 67% reporting they never label dentures. Dental Prosthetists are significantly more likely to perform denture labelling compared to General Dentists.

When reflecting on practitioner education, 64% were never taught how to label dentures, which may explain the low adoption of denture labelling practice and highlights an opportunity for curriculum enhancement. Among those who did label dentures, inclusion techniques are preferred with plastic strips (47%) and paper (41%) being the most common methods. The majority of practitioners (67%) use the patient's name as the identification information on dentures.

For full upper dentures, the posterior palatal base area (44%) and posterior buccal flange area (42%) are the preferred locations for marking. For full lower dentures, the posterior lingual base area (48%) and posterior buccal flange area (40%) are most commonly selected. It's noteworthy that some respondents mentioned labelling mouthguards and implant-supported dentures, indicating a broader potential application for denture labelling.

Despite low implementation rates, 67% of practitioners are aware of the forensic applications of denture labelling, and 75% would support mandatory denture labelling in hospitals and aged care facilities. This suggests that practitioners recognise the value of denture labelling even if they don't regularly practice it. This might be explained through the identified primary barriers to denture labelling which included time constraints and labour requirements. Patient privacy concerns were rated lower (mean score: 2.65), and the perception that denture labelling is not useful received the lowest barrier score. [2,33]

Comparative investigations were completed by Alexander, Taylor [24] in South Australia (SA) looking at general dentists. That study documented that 19.9% of participants reported labelling dentures on some occasions and 50% said that denture labelling was not useful. Cost was cited as a barrier by 25% of participants. A high proportion of participants were aware of denture labelling techniques, with only 12% reporting they did not, compared to 63.5% who were not taught in the present study. This comparison indicates that denture labelling techniques were taught more previously but due to the perceived lack of relevance, the education practice has diminished.

Many practitioners may be unaware of the existing Australian Nursing Home Standards of 1987 for "discreet labelling" of residents' dentures. Additionally, 63% of practitioners were not aware of the ADA code #777 for marking dental appliances with patient identification. Both of these areas indicate a potential area for improvement in dental education and awareness of existing guidelines and standards related to denture labelling.

Practitioners exposed to forensic odontology during their education showed significantly stronger support for mandatory labelling in institutional settings. The majority (67%) were aware that denture labelling could aid in the identification of deceased individuals. There was some variation in recording denture label details in patient dental records, with 39% of practitioners doing so, 36% not doing it, and 25% being unsure. This inconsistency in record-keeping practices may have implications for the forensic utility of denture labelling. This is highlighted in the ADA Policy Statement 6.16 on Forensics in Dentistry: "dentures should be marked with the patient's name and such marking noted in the dental record". [34] The lack of information, such as denture label details in the patient dental records, may result forensic dental identification may not be suitable for use, and instead different forensic identification modalities might be required.

Based on the educational gaps identified in this survey, it is recommended that denture labelling is incorporated into dental and prosthodontic curricula. It is recommended that standardised guidelines be developed to promote consistent practises and mandatory policies for aged care facilities and hospitals where higher levels of practitioner support are available. This can be advocated through various health associations such as ADA, nursing associations, etc. There is a need to increase awareness among practitioners about the benefits of denture labelling would be required, particularly its forensic application, and recording the information in patient dental records as stated in the ADA Policy Statement on Forensics in Dentistry. Comprehensive and accurate dental record is not only important for forensic purposes, it is also required for medico-legal purposes. The importance and raising awareness of dental record keeping and the ADA Policy Statement 6.16 can be conducted through regular ADA CPD activities including collaboration with Australian dental schools. Lastly additional research should be conducted on patient attitudes and experiences with denture labelling to gain a more comprehensive understanding of the issue.

The sample size of practitioners limits the generalizability of findings. The sampled population was one of convenience and does not necessarily represent all dental practitioners in Australia; however, the sample size was still able to identify clear trends. There was sampling bias amongst the locations (Queensland and New South Wales) and types of practitioners. Being a survey, the data is self-reported and subject to inaccuracies.

CONCLUSION

Denture labelling remains an underutilised practice in Australia, even though surveyed practitioners show recognition of its value. This study has identified significant gaps in dental education regarding denture labelling techniques. Dental Prosthetists and more experienced practitioners are more likely to implement denture labelling. There is substantial support for mandatory denture labelling in institutional settings despite the primary barriers of time, labour and cost.

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Curvature-based 3D dental comparison to identify trauma-induced surface changes in human teeth: a forensic comparison study

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3D Scanning

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ABSTRACT

This study evaluates the performance of a curvature-based 3D dental comparison method - the keypoint pipeline - for forensic identification, assessing the effects of standardised blunt force trauma on human dentitions.

The dental arches in ten human jaw specimens (five maxillae, five mandibulae) were scanned using two intraoral 3D scanners before and after exposure to controlled blunt trauma delivered via a drop tower mechanism applying approximately 3154 Newton of force. Trauma outcomes were documented through high-speed video, digital photography, and 3D scanning. Post-trauma scans were processed using the keypoint pipeline, which quantifies dental surface similarity by comparing curvature signatures. An all-vs-all comparison was conducted between pre- and post-trauma scans, including cross-scanner evaluations.

Despite consistent trauma application, fracture patterns varied by jaw type, with mandibular fractures typically occurring in the frontal plane in the side segments and maxillary fractures in the sagittal plane in the midline suture. The keypoint pipeline successfully scored 92.5% of the true matches to be the best matching comparison, even in the presence of significant structural damage and tooth displacement. Matching pairs yielded lower dissimilarity scores (mean: 0.55) compared to mismatches (mean: 0.78), indicating that curvature features were sufficiently preserved post-trauma.

These findings support the integration of curvature-based 3D dental surface analysis into forensic odontology workflows, particularly in disaster victim identification scenarios involving blunt force trauma.

INTRODUCTION

In the case of disasters, countries with a membership in INTERPOL have the option of calling on assistance from Disaster Victim Identification (DVI) services and an Incident Response Team, to help with identifying the victims.[1]. According to INTERPOL three primary identifiers are used for disaster victim identification, namely DNA, fingerprints and dental comparison.[1-4] For dental comparison, a forensic odontologist will compare the *post mortem* (PM) dentition with information from *ante mortem* (AM) dental records of possible victims to find identifying traits.[1-6]

When comparing an AM dental record with a PM dentition, the forensic odontologist relies on congruence between the descriptions in the AM dental record and the PM dentition.[1-6] A description could be the placement of fillings or crowns, or agreement between AM and PM X-ray images.[1-6] In the absence of dental work, such congruence can be difficult to establish.

In recent years, efforts have been made to digitize parts of the dental comparison, by comparing AM 3D intraoral scans with PM 3D intraoral scans.[7-18] Such a comparison can potentially quantify dentition similarity, even when there is no dental work, giving the forensic odontologist an advantage when comparing dentitions. A quantitative similarity score can both be used to give an indication of identity, while it can also be used to sort the AM dental records for examination, especially in disasters with many victims.[11,14,17] Furthermore, such a method helps to address past criticism of the discipline as being excessively subjective.

So far, these 3D comparison studies have investigated various scenarios, including single, extracted teeth, heat exposure and digital partialisation.[11,14,17]

In a disaster, the dentition might be subjected to blunt force trauma in various ways.[19] It could be impacted from a traffic/high-speed incident, falling from great heights, explosions or other high-impact scenarios.[19] Even though the teeth are the hardest material in the human body and they are very resistant to many types of traumas, many trauma scenarios are still expected to have an impact on the dentition surface.[6,19]

Dental blunt force trauma has been described in a forensic context, but to the best of our knowledge there has not been any study on the quantitative dental similarity of human dentitions before and after exposure to blunt force trauma.[19,20] After exposure to blunt force trauma, at least part of the dentition surface is expected to have changed. These changes could include, but are not limited to, infractions, enamel chipping off, fractured teeth, and missing teeth. Such changes to the dentition surface could potentially disturb automatic dental surface comparison to a great extent.[11,14,17] Previously the keypoint pipeline methodology for automatic 3D dental comparison within forensic odontology identification has been proposed.[11,14,17] But since this methodology relies on key surface curvatures to be present in both AM and PM data, blunt force trauma might constitute a problem for the methodology. But to what extent blunt force trauma might interfere with dental comparison using the keypoint pipeline has yet to be investigated.

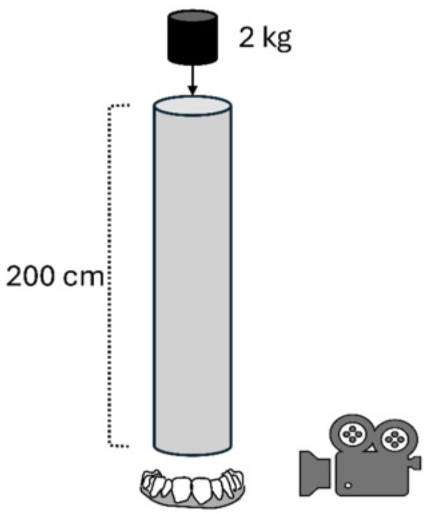
This study aims at testing the previously developed keypoint pipeline method for quantitative dental comparison, specifically on human dentitions subjected to blunt force trauma.[11,14,17] This study therefore aims at testing the robustness of the keypoint pipeline for dental comparison in a context where the dentition surface is expected to have changed to some degree. Furthermore, the combination of both descriptive and quantitative comparison of human dentitions before and after blunt force trauma will add to the understanding of dental surface changes in blunt force trauma scenarios.

MATERIALS AND METHOD

This *ex vivo* study was exempt from ethical approval (request 279/2017). The specimens were obtained from individuals who had donated their bodies to science; no information regarding the donors' gender, age, or cause of death was available. All procedures were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

A total of 5 upper jaws and 5 lower jaws were scanned using two 3D intraoral scanners (PrimeScan AC and PrimeScan Connect, Dentsply-Sirona, Bensheim, Germany) before and after being subjected to standardised experimental blunt force trauma. To ensure that the results were not dependent on scanner-specific characteristics, two structurally equivalent scanners were used. Although both systems share the same mechanical design principles, they were manufactured at different times; one as a stationary model and the other a mobile version operating with a newer software release. The scanning of the dentitions started on the left-most molar and moved in a zig-zag pattern from the occlusal surfaces to the lingual surfaces, back to the occlusal surfaces, and onto the buccal surfaces, moving across the entire dentition. Followingly, any missing surfaces were re-scanned after a visual inspection. This scanning pattern was adhered to as strictly as possible, as was recommended by the manufacturer (personal communication). The jaws were kept stationary on a tabletop, to ensure that individual parts weren't moved relative to one another after trauma. The initial impact of the trauma was estimated to be 3,154 Newton, equal to approximately 321 kilograms of force (see supplementary material 1). Inspired by Houg et al. [20] the blunt force trauma setup was in the style of a drop tower, where a weight (2 kg) was being dropped from a fixed height (200 cm) directly onto the approximate occlusal plane of a fastened jaw, fastened to a rigid surface. Details of the trauma setup can be seen in Figure 1 and can be found in the experiment protocol in Supplementary Materials 1.

Figure 1. Experimental setup of the standardised blunt force trauma. A 200 cm drop was ensured by a pipe, guiding the falling object which weighed 2 kg. A high-speed camera recorded the impact to estimate the force of the impact.



The specimens were documented in the style of 3D scans and digital photos before and after the experiment, and the blunt force trauma was documented with high-speed camera footage during the impact.
The soft tissue part of the 3D scans was manually removed from all 3D scans, before subjecting them to keypoint detection and keypoint representation as described by the keypoint pipeline.[11,14,17] Due to the high force impact on the jaws, and the resulting irregular dental surfaces, manual soft tissue removal was required. To avoid different treatment of samples before and after trauma, soft tissue was manually removed from both instances. The soft tissue removal was performed in Blender.[21] The keypoint pipeline is a previously proposed processing pipeline that compares curvature signatures on the dental surfaces between 3D dental scans in STL mesh format to quantitatively evaluate similarity.[11,14,17] Since the position of some of the teeth changed during the trauma, the keypoint placement factor was disregarded from the scoring scheme when comparing dentitions.[17] This is not expected to change the performance of the keypoint pipeline scoring scheme, as the contribution of keypoint placement to the final score has been observed to be minimal, and the score without this factor has been reported to perform almost as well.[17] In this study, a score closer to zero would indicate a match, and a score closer to one would indicate a mismatch, as the scoring scheme indicates dissimilarity.[14,17]
The comparisons were made in an all-vs-all manner, where all the scans before trauma were compared with all the scans after trauma, including comparisons between the two different scanners.

RESULTS

Even though the trauma exposure was standardised by a drop tower, the trauma seen in the specimens varied significantly. Figure 2 shows the progression of the blunt force trauma exposure for one of the specimens.
During the experiment, all 10 jaws suffered trauma to the bone and dental structures. For the lower jaws, fractures were mostly seen in the frontal plane, between canines and premolars, between premolars and molars (Figure 3), or between molars, while for the upper jaws' fractures were observed in the sagittal plane in the midline suture (Figure 4). Tooth crown fractures were observed to varying degrees in both upper and lower jaw specimens (Figure 4 and 5). A single specimen appeared with comprehensive fixed prosthodontics and suffered multiple root fractures and displacement of all teeth. More teeth were seen to be intruded in the lower jaws (Figure 6) and displaced in the upper jaws. A tooth exarticulation occurred in two lower jaws (Figure 3), while more prosthetic work was separated from the tooth abutments/lost due to root fractures in the upper jaws.
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between premolars and molars (Figure 3), or between molars, while for the upper jaws' fractures were observed in the sagittal plane in the midline suture (Figure 4). Tooth crown fractures were observed to varying degrees in both upper and lower jaw specimens (Figure 4 and 5). A single specimen appeared with comprehensive fixed prosthodontics and suffered multiple root fractures and displacement of all teeth. More teeth were seen to be intruded in the lower jaws (Figure 6) and displaced in the upper jaws. A tooth exarticulation occurred in two lower jaws (Figure 3), while more prosthetic work was separated from the tooth abutments/lost due to root fractures in the upper jaws.

Figure 2. Still photographs of a mandibular specimen (ID05) during the experimental blunt force trauma. This specimen, in particular, suffered significant damage during the experiment. Time indicates milliseconds (ms) from first impact.

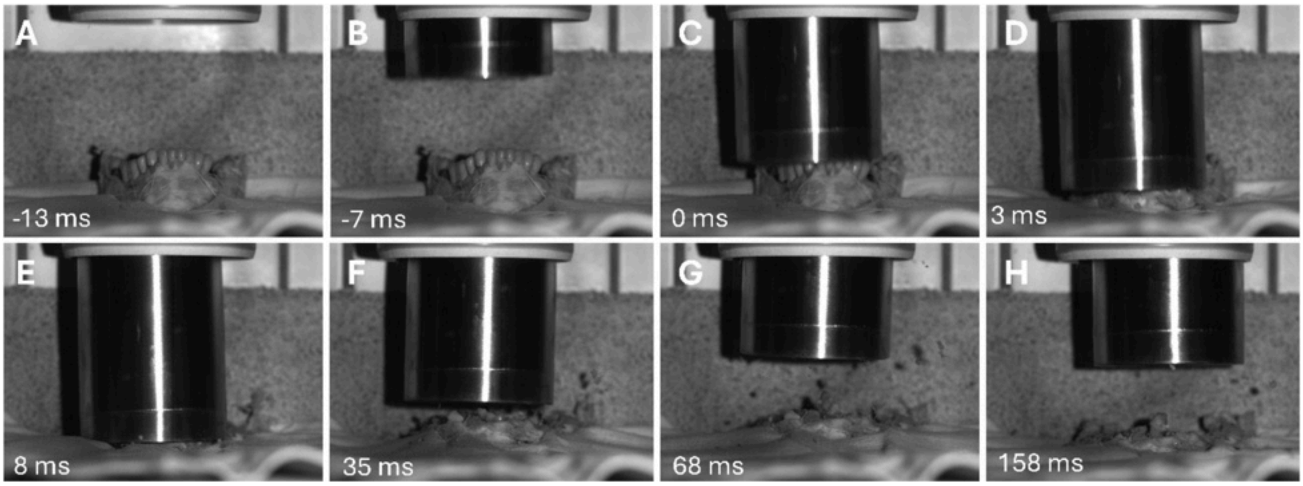


Figure 3. One of the mandibular specimens (ID02) before (A, B, and E) and after the experimental trauma (C, D, and F). The white arrow in C) points at tooth 45 that was exarticulated from the alveolar socket. A jaw fracture between tooth 35 and 36 displaced the posterior left part of the mandible (black arrows in C) and D)). The anterior segment was found intact. Figure E and F show the dental meshes after soft tissue removal.

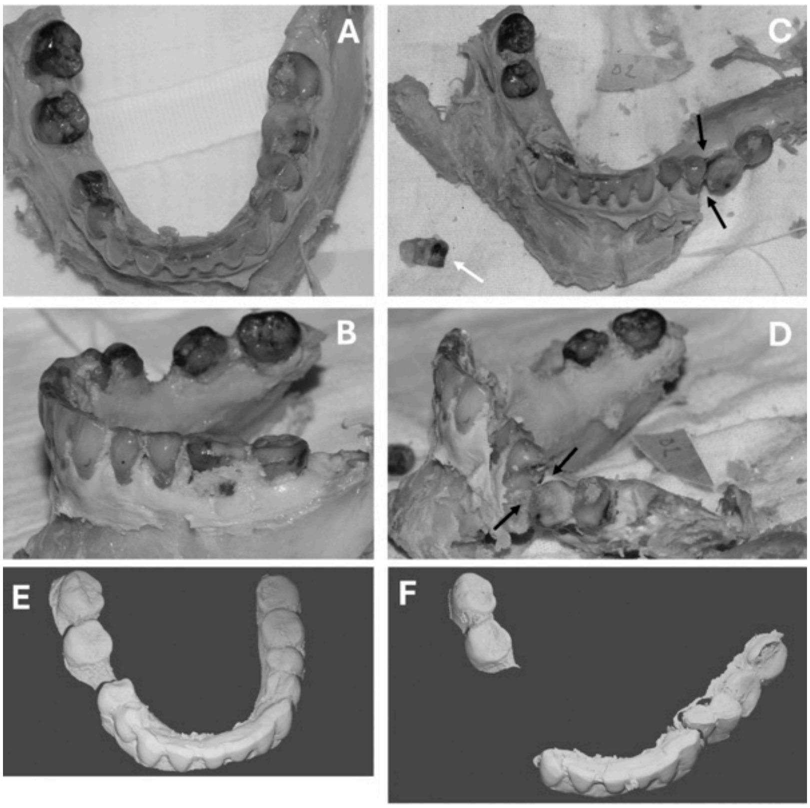


Figure 4. One of the maxillary specimens (ID10) before (A,B, and E) and after the experimental trauma (C, D, and F). The white arrows point at areas with obvious damage to the enamel (tooth 16, 14, 11 and 26). The black arrows mark a distinct fracture line along the maxillary midline suture (sutura palatina mediana). Figure E and F show the dental meshes after soft tissue removal.

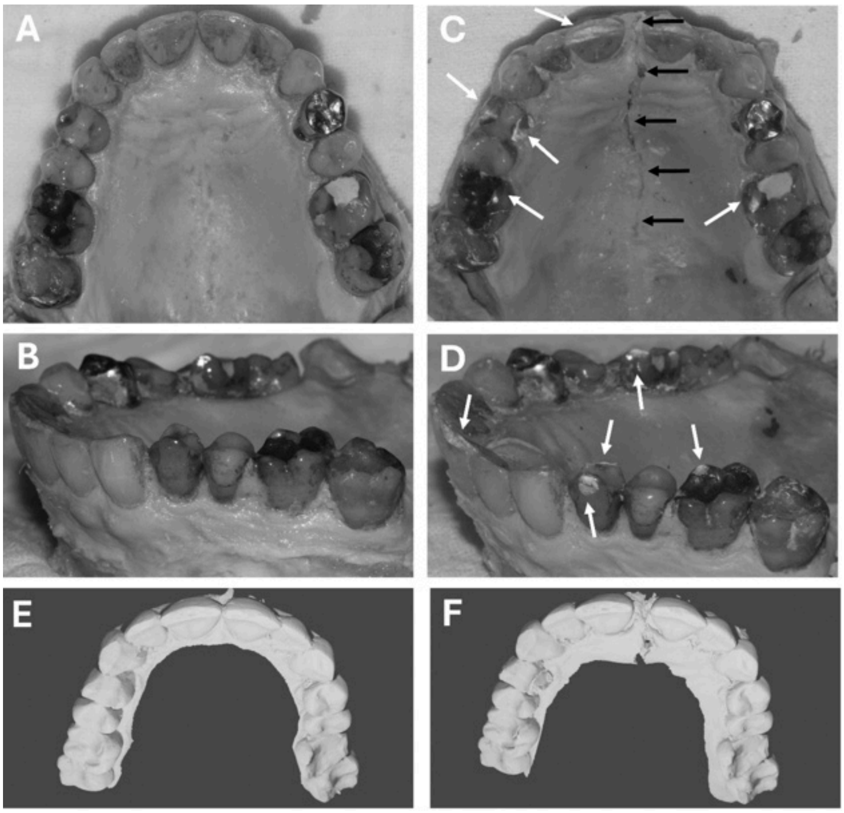


Figure 5. One of the mandibular specimens (ID04) before (A, B, and E) and after the experimental trauma (C, D, and F). The white arrows point at teeth where substantial parts of the tooth crown / restorative treatment suffered extensive damage during the test. In C) the prosthetic partial crown from tooth 46 can be seen broken next to the jaw (black arrow). Figure E and F show the dental meshes after soft tissue removal.

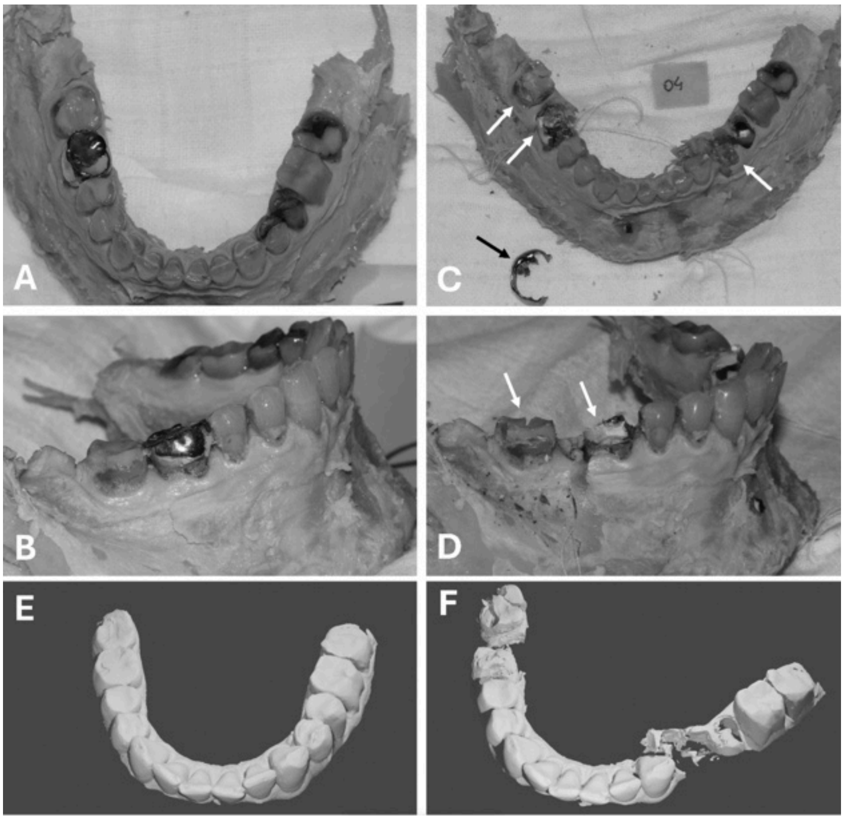
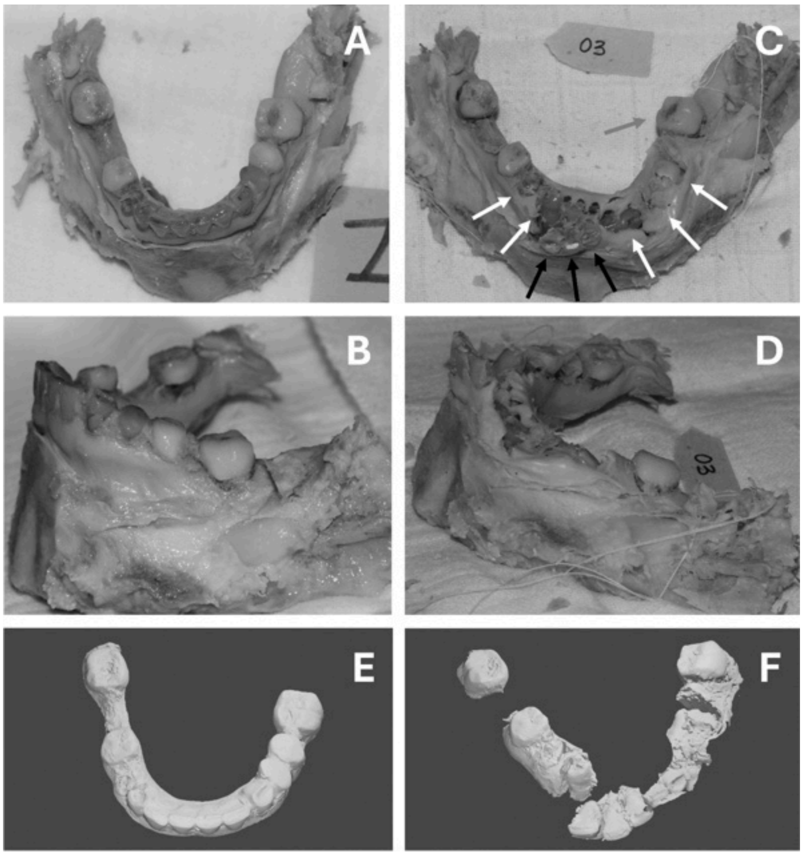


Figure 6. One of the mandibular specimens (ID03) before (A, B, and E) and after the experimental trauma (C, D, and F). The white arrows in C) point at tooth 44, 43, 33, 34 and 35 that were severely intruded into the bone. Teeth 42, 41 and 31 were displaced facially from their alveolar sockets (black arrows in C)) and 36 displaced lingually (grey arrow in C)). Figure E and F show the dental meshes after soft tissue removal.



When quantifying dentition surface similarity using the keypoint pipeline, the dissimilarity score was in most cases able to differentiate between matches and mismatches, despite the use of different scanners and the extensive destruction due to blunt force trauma. This is seen by the dark-colored diagonal in Figure 7.

A total of 20 dentition surfaces after trauma were quantitatively compared to the 20 dentition surfaces prior to trauma, giving 20x20 dissimilarity scores. For each post-trauma dentition, there were two comparisons which would constitute a match, one from the same scanner, and one from a different scanner, leaving the remaining 18 comparisons as mismatches.

For 17/20 of the post-trauma dentitions, both matches were the lowest scoring comparisons. For the remaining 3/20 (ID03p, ID03s, ID05p), one of the true matches was the lowest scoring comparison, 1/3 (ID03p) being the match from the same scanner. The scores of each comparison can be seen in Figure 7, and the distribution of dissimilarity scores for matches and mismatches can be seen in Figure 8.

Since the keypoint pipeline was branded as a relative scoring scheme,[11,14,17] it was not intended to be able to establish an absolute classifier threshold. Nevertheless, a difference between the absolute scores given to a match versus the scores given to a mismatch is seen, with matches scoring on average 0.55 (95% PI 0.40 to 0.75) and mismatches scoring on average 0.78 (95% PI 0.71 to 0.83) (Figure 8).

Figure 7. Matrix of dissimilarity scores for each jaw. The id numbers are noted with a p or an s indicating the two scanners and t for post trauma.

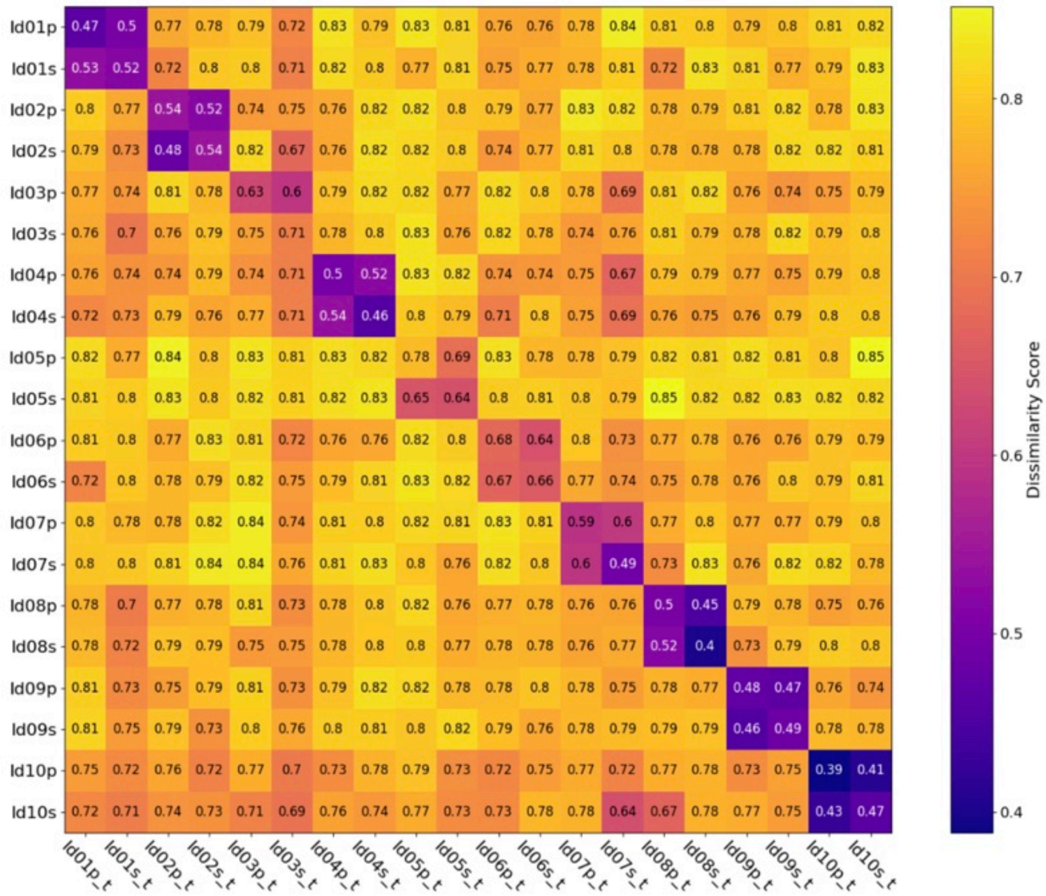
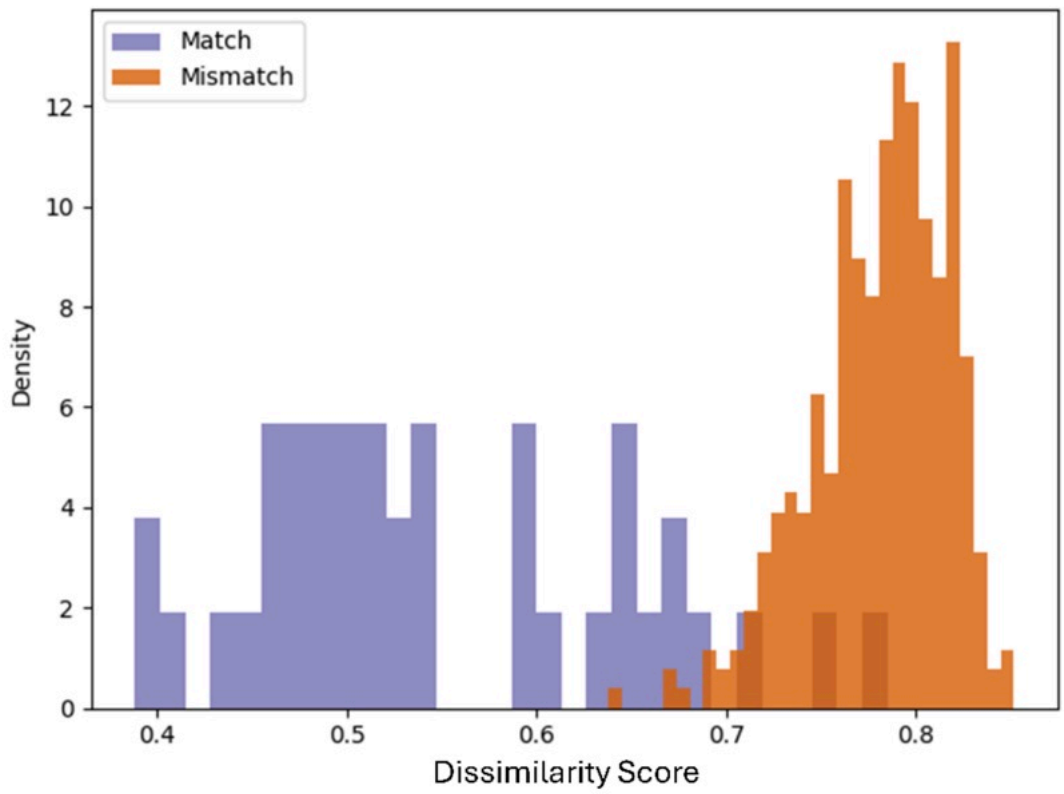


Figure 8. Density distribution of the dissimilarity scores classified by matches and mismatches



DISCUSSION

The reliable identification of disaster victims, despite severe post-mortem trauma and environmental degradation, remains a matter of high forensic and humanitarian importance.[6,11,14,22,23]

This study explores the impact of an experimental blunt force trauma on human dentitions. It does so in two parts: one being the descriptions of the dental and bone changes caused by direct blunt force trauma to the approximate occlusal plane to the specimens; the other being the exploration of quantitative dental similarity scoring before and after the blunt force trauma.

In the case of blunt force trauma, this study shows that the curvature signatures on the dentition surface may be preserved enough to show differences between matches and mismatches. Even though this study doesn't aim at showing an absolute difference in the scores given to matches and mismatches, Figure 7 shows a relative difference in scores, while Figure 8 shows a distinct tendency of difference of absolute dissimilarity scores. This is in line with the intended use of the scoring scheme, as previous publications have underlined its use as an ordering algorithm.[11,14,17] It is hypothesized that a larger difference in dissimilarity score between the lowest and 2nd lowest value will indicate a higher confidence match.

One specimen, ID03, proved more difficult to quantitatively score. This specimen showed both tooth displacement and tooth intrusion, as seen in Figure 6. Nevertheless, at least one of the matching scans for this specimen was scored as the best match, proving that even in such difficult cases, the keypoint pipeline can be of use.

This study is to be seen as an extension of the previous publications regarding the keypoint pipeline.[11,13,14,17] On its own, this study suffers from a limited sample size, as it only includes 10 jaws, and it suffers from a lack of diversity, as it only investigates one type of standardised trauma. Favorably, the specimens comprised a sample of jaws holding a random number of teeth with varying amount and type of dental work, which can be seen as a strength – mimicking a real-life scenario. Though, the results indicate that these parameters, besides jaw type, influenced the resulting types of traumas to both bone and dental structures. But this study is an essential puzzle piece that adds to the confidence in the keypoint pipeline as a tool for the diverse landscape of disaster victim identification.

In regard to trauma, this study lacks variation of the impact, such as variations in trauma direction and inclusion of protective tissue that would be seen in a real-life disaster case.[14,19,20] But to investigate a trauma scenario, standardised trauma allows for systematic investigations of the effects of the trauma, limiting the degrees of freedom. Therefore, this study is limited to investigating the effect of direct blunt force impact on the visible dental surfaces. For future larger trauma studies, more real-life-like scenarios could be established.

The descriptions of the observed tissue destructions in this study add to the understanding of dental surface changes in disaster scenarios featuring blunt force trauma. From Figures 2-6, it is seen that there are extensive changes to the dentition surface, as described in the results section.

Whether the individual curvature signatures on the teeth are preserved well enough for quantitative dental comparison, despite trauma, has not previously been investigated, to our knowledge. Apparently, such an investigation has been limited by the lack of quantitative dental similarity measures that are tooth-position independent. But, with the suggested keypoint pipeline, it is now possible to score curvature similarities of the dentition surface despite displacement.[11,14,17] For such a similarity measure to be proven suitable for the vast diversity of disasters, its performance must be evaluated in a variety of trauma scenarios, including blunt force trauma. The keypoint pipeline has previously been tested in the case of partial jaws, single teeth, and in heat trauma scenarios.[11,14,17] This study extends this list of scenarios where the keypoint pipeline has proven useful.

In conclusion, this study shows that the keypoint pipeline and scoring scheme is able to distinguish 3D dentition surfaces from matching identities and mismatching identities, even in the case of substantial blunt force trauma. It can do so to such an extent that indicates that the pipeline can be a positive addition to the forensic odontology process regarding disaster victim identification.

Further studies, focusing on diverse and more complex trauma patterns are suggested as an obvious next step, before the method can be judged as acceptable for application in a real disaster scenario.

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ETHICS AND CONSENT TO PARTICIPATE

All specimens in this study were obtained from individuals who had donated their bodies to science through the donation scheme at the Department of Biomedicine at Aarhus University and were kept anonymized. No jaws were obtained from prisoners.

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Utilisation of non-dental radiographs in forensic dental identification of unknown human remains: a Queensland case series

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Radiology,
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ABSTRACT

Forensic odontology is one of INTERPOL's three primary identifiers for Disaster Victim Identification (DVI). Forensic dental identification relies on the availability of antemortem dental radiographs, such as orthopantomogram (OPG), dental cone beam computed tomography (CBCT) scanned images, bitewing, and periapical (PA) views. These antemortem dental radiographs are used for comparison with postmortem dental radiographs. However, there are other types of non-dental medical radiographs that also capture dental structures. These medical radiographs are proven to be useful in forensic dental identification. This Queensland case series highlights the importance of non-dental radiographic images for the purpose of forensic dental comparison including the first published forensic dental identification involving comparison of a postmortem computer tomography (PMCT) multiplanar reformat (MPR) image with non-dental antemortem radiography. This case series also highlights the benefits of a collaborative working relationship between the forensic odontologist, forensic pathologist, police, and Coroner, in antemortem data collection.

INTRODUCTION

A mass casualty incident is when the incident overwhelms conventional emergency service resources.[1] Disaster Victim Identification (DVI) is the structural evidence-based forensic process to identify the deceased victims in a mass casualty incident. The INTERPOL DVI Guide states that forensic odontology is one of the three primary identifiers along with deoxyribonucleic acid (DNA) studies, and fingerprints.[2] Forensic dental identification, one aspect of forensic odontology, involves the use of both antemortem and postmortem dental data to reach a dental identification conclusion. Dental radiography is one of the many types of dental data,[3] and it is the preferred data due to its objectivity, unlike written dental records, which can be quite subjective. There are several medical radiographs that capture oral and dental structures, such as skull radiographs including antero-posterior (AP), postero-anterior (PA) and lateral views, and cervical spine view radiographs.[3-5] Generally medical radiographs may not provide close-up views of the oral and dental structures, however some of these captured features can be used for forensic dental identification as described in this Forensic Pathology and Coronial Services (FPaCS) case series.

CASE SERIES

Case 1:

A deceased adult male was found incinerated in a vehicle with no identifiable features due to severe charring and blackening across most of the body. The body was transported to the mortuary for coronial identification. The antemortem dental data consisted of written dental records. The written dental records indicated only teeth 18, 38, and 48 had been extracted and that a filling had been placed on tooth 47. A postmortem computed tomography (PMCT) scan was carried out as part of the mortuary standard operating procedure (SOP). The FPaCS Computed Tomography (CT) Scan is the Siemens SOMATOM Definition AS Open (Siemens Medical Solution, USA), and as part of the mortuary SOP, all remains received by the mortuary will require a PMCT scan. The PMCT showed that teeth 18, 38 and 48 were absent and tooth 47 was absent, although there were some similar features with the dental records, the information was insufficient for any meaningful dental comparison. The forensic odontologists located medical CT images of the person believed to be the deceased adult male from one of the private radiology centres. The mid-face CT of the head was taken to investigate intracranial lesions. There were distinctive tooth root forms in the upper left quadrant of the antemortem mid-face CT image which were comparable to the root forms in the upper left quadrant of the PMCT image. The roots of the upper left dental quadrant of the antemortem mid-face CT image were superimposed over the image of the roots of the teeth of the upper left dental quadrant of the PMCT image (Figure 1(a)-(f)). This method along with the findings of the dental records was sufficient to complete the forensic dental identification of the deceased adult male.

Figure 1. (a)-(f) shows the superimposition of the upper left teeth roots of the antemortem mid-face CT image over the PMCT image

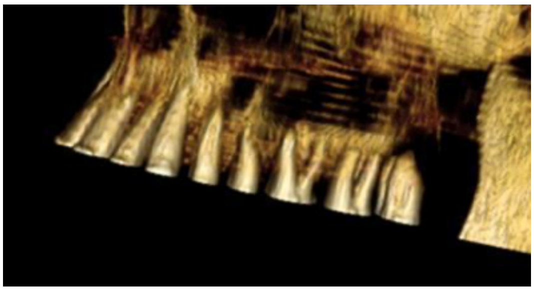


Figure 1. (a) upper left teeth roots of the antemortem mid-face CT with 100% opacity over upper left teeth roots of PMCT.

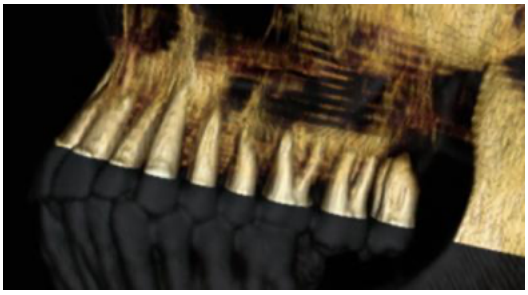


Figure 1. (b) upper left teeth roots of the antemortem mid-face CT with 80% opacity over upper left teeth roots of PMCT.

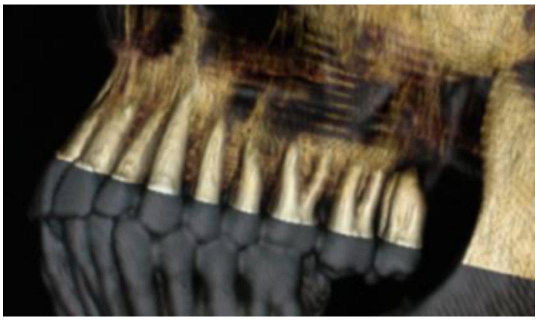


Figure 1. (c) upper left teeth roots of the antemortem mid-face CT with 60% opacity over upper left teeth roots of PMCT.

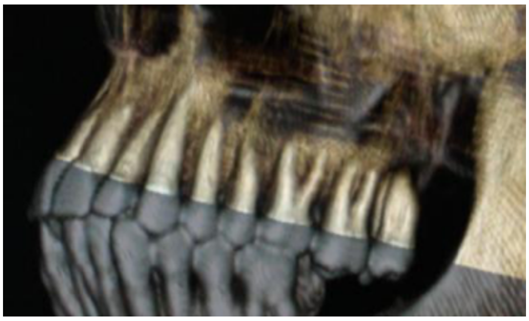


Figure 1. (d) upper left teeth roots of the antemortem mid-face CT with 40% opacity over upper left teeth roots of PMCT.

Figure 1. (e) upper left teeth roots of the antemortem mid-face CT with 20% opacity over upper left teeth roots of PMCT.

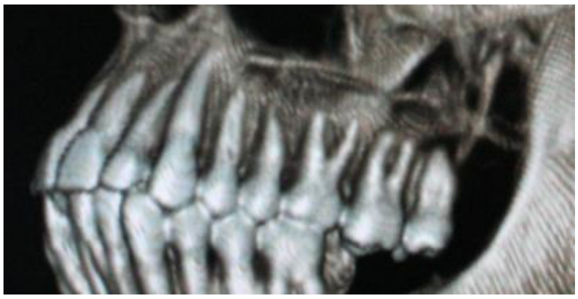


Figure 1. (f) upper left teeth roots of the antemortem mid-face CT with 0% opacity over upper left teeth roots of PMCT.

Case 2:

A 23-year-old deceased male was involved in a motor vehicle crash. The male was ejected from the vehicle resulting in death due to major body and skull trauma. The body was transferred to the mortuary for coronial identification. Antemortem dental data consisted of two lateral cephalogram radiographs and written dental records, however, these radiographic images provided minimal dental information that could be used for forensic dental identification. The written dental records noted that the person believed to be the deceased male had undergone jaw surgery. With this information, the forensic odontologists conducted a search of one of the private radiology centres and retrieved postoperative CT images of the person believed to be the deceased male (Figure 2(a), and Figure 3(a)). The postoperative CT images showed placements of multiple metal surgical plates in the body and ramus of the right mandible, and in the zygomatic and frontal process of the maxilla. PMCT of the deceased male was taken as part of the mortuary SOP (Figure 2(b), and Figure 3(b)). 3D CT images from the postoperative CT, and the PMCT were compared. Both 3D images showed multiple concordant features such as the locations of the surgical metal plates, and dental root morphologies. This method along with the findings of the dental records was sufficient to complete the forensic dental identification of the deceased adult male.

Figure 2. Comparison of Figures 2(a), and 2(b): there is complete correspondence in the placement of the surgical metal plates in both images. There is also concordance of the dental root morphologies. There are no unexplained discrepancies. Orthodontic brackets are present in the antemortem postoperative image but not present in the PMCT image. The removal of orthodontic brackets was documented in the antemortem dental records.

Figure 2(a): Antemortem postoperative CT image.

Figure 2(b): PMCT image.

Figure 3. Comparison of Figures 3(a), and 3(b): there is complete correspondence in the placement of the surgical metal plates in both images. There is also concordance of the dental root morphologies. There are no unexplained discrepancies. Orthodontic brackets are present in the antemortem postoperative image but not present in the PMCT image. The removal of orthodontic brackets was documented in the antemortem dental records.

Figure 3. (a) Antemortem postoperative CT image.

Figure 3. (b) PMCT image.

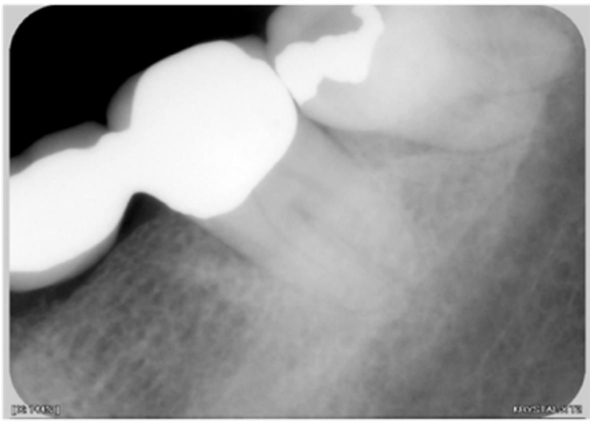
Case 3:

The remains of a deceased person were recovered following a light aircraft crash. No antemortem dental imaging was available. However, a series of cervical spine radiographs was located including antero-posterior, lateral, oblique, and odontoid views. Multiple distinctive dental features were visible on the oblique view including multiple metallic restorations, teeth 35-37 bridge, teeth 25, 26 and 27 crowns, and root canal treatment (RCT) of teeth 26, and 27 (Figure 4). PMCT multiplanar reformat (MPR) images were produced from the PMCT scanned data of the deceased. Due to artefacts precluding detail within the images, postmortem plain film dental radiographs were taken (Figures 5(a), and 5(b)), and compared to the antemortem oblique cervical spine radiograph. Multiple concordant features with no unexplainable discrepancies were noted, and this comparison was found to be sufficient to establish the identity of the deceased.

Figure 4. Antemortem oblique cervical spine radiograph of person believed-to-be the deceased. Multiple distinctive dental features are noted including multiple metallic restorations, a lower posterior bridge and upper posterior crowns and root canal treatments.

Figure 5. (a) Upper left side PA radiograph of deceased's dentition. The pattern of metallic restorations, crowns and RCT corresponds to the antemortem radiograph, except for the tooth 28 restoration, which has been replaced since the antemortem radiograph was taken.

Figure 5. (b) Lower left side PA radiograph of deceased's dentition. The teeth 35-37 bridge, and the distinctive morphology of the tooth 38 metallic restoration correspond to the antemortem radiograph.



Case 4:

The remains of an adult male were recovered following a motor vehicle crash. No dedicated antemortem dental imaging was available, however, a cervical CT scan taken for a non-dental indication was located at a private radiology provider. Multiple distinctive dental features were visible on the antemortem CT including multiple missing teeth, and RCT of teeth 31 and 41 (Figures 6(a), and 6(b)). Axial sections and PMCT MPR images were produced from the PMCT data of the deceased (Figures 7(a)–(c)), and compared to antemortem CT axial sections and written dental records. Multiple concordant features with no unexplainable discrepancies were noted, and this comparison was found sufficient to establish the identity of the deceased.

Figure 6. (a) Antemortem CT axial section of upper teeth demonstrating multiple missing teeth.

Figure 6. (b) Antemortem CT axial section of lower teeth demonstrating RCT of teeth 31 and 41 and missing teeth 36, 38, 46 and 48.

Figure 7. (a) PMCT axial section of upper teeth demonstrating multiple missing teeth. The pattern of missing teeth, as well as the positions and dispositions of remaining teeth, are concordant with the antemortem CT images.

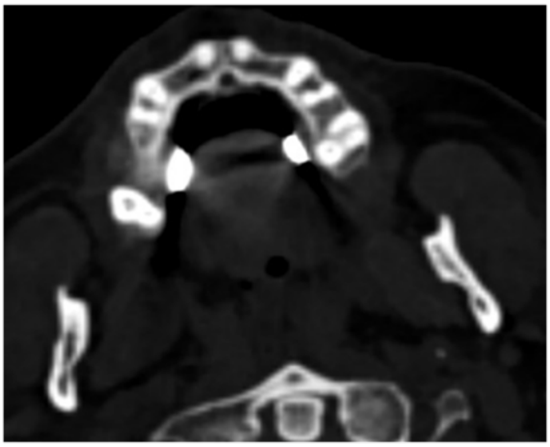


Figure 7. (b) PMCT axial section of lower RCT of teeth 41, 31 and 32. Teeth 36, 38, 42, 46 and 48 are missing. Written clinical dental notes confirm that the RCT of tooth 32 and the removal of tooth 42 were performed after the antemortem CT was taken.

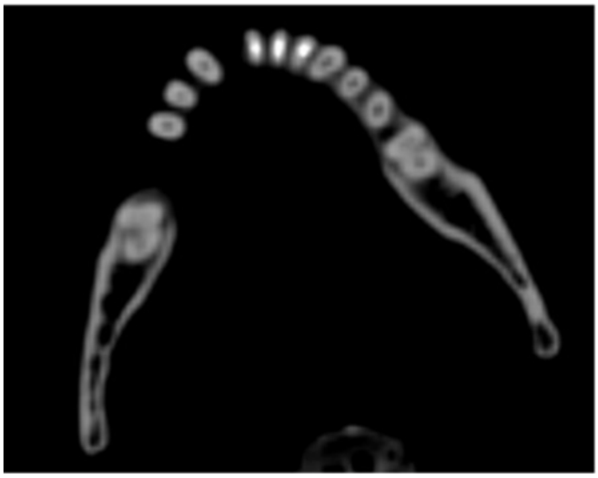
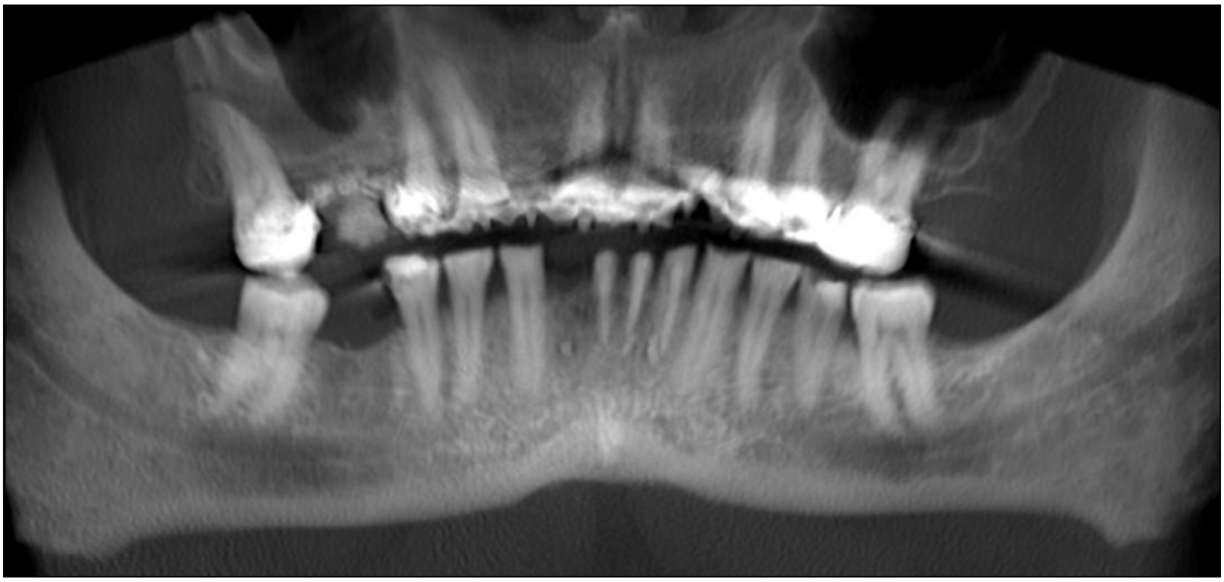


Figure 7. (c) PMCT MPR image of the upper and lower jaws demonstrating those features noted in 7(a) and 7(b). Note that the deceased was wearing a partial upper metal-based denture when the PMCT was taken.



DISCUSSION

Forensic dental identification involves the comparison and reconciliation of antemortem and postmortem dental data to reach a conclusion; antemortem and postmortem dental comparison could be as simple as comparing written dental records or as complex as utilising microscopy and elemental analysis.[6-9] Useful antemortem dental data includes: written dental records, dental radiographs, dental casts, and dental prostheses. It is important to note that having minimal or no antemortem dental data means it can be difficult or impossible to provide a meaningful forensic dental comparison.

A literature review was completed on 30 March 2025 in the use of non-dental radiographs or x-rays on PubMed using the terms: non-dental,

medical, identifications, identification, radiographs, radiograph, x-ray, and x-rays.
Three articles that were related to this topic were identified.[3-5] The antemortem medical radiographs that were used for forensic dental identification in these articles were lateral cervical spine, trans-oral cervical spine, scout view of skull CT, sagittal CT view of skull, and anteroposterior view of skull. All cases in these articles led to a successful outcome in identification of the unknown human remains. This Queensland case series also demonstrated successful outcomes of identification of deceased persons using non-dental antemortem radiographs. Both the located articles and the Queensland case series show the usefulness of medical radiographic images in forensic dental identification.
Medical radiographs, particularly AP and PA skull views, lateral skull view, and cervical spine view radiographs are often prescribed by medical clinicians for investigation of skull fractures, neoplastic changes, or Paget's disease.[10,11] Often these radiographs will show dental structures. The deceased person's medical condition or history are good indicators of potential medical radiographs that they may have had taken in the past. The forensic pathologist is essential in the death investigation of the deceased person.[12] The coronial investigation process often involves the autopsy of the deceased person. Based on the autopsy findings, the forensic pathologist could advise the forensic odontologist of the possible medical radiographs, related to the head and neck region, that the deceased person may have had in the past.
Since 1895, medical imaging has come a long way, evolving from the first medical radiograph taken by Roentgen, to CT scanning in 1971, and nuclear magnetic resonance (NMR) imaging in 1973.[13] In the forensic pathology and medicine context, plain film medical radiography was first used in 1896 involving a gunshot wound investigation, and in 1921, medical radiographs were first used for forensic identification.[14,15]
FPaCS acquired its first Multi-Slice Computed Tomography (MSCT) scanner in 2009. Since then, all deceased persons who require coronial investigation, were PMCT scanned as part of the mortuary SOP. FPaCS forensic odontologists have routinely conducted forensic dental identification utilising PMCT including its MPR and 3D reconstruction images since 2011. In the earlier years, postmortem dental data retrieved from PMCT was used in conjunction with the postmortem dental records and intraoral dental radiographs. Since 2019, FPaCS forensic odontologists have regularly completed forensic dental identification casework using PMCT MPR without the need to take postmortem dental records and intraoral dental radiographs. The forensic odontologists work closely with FPaCS forensic radiographers in producing these MPR and 3D reconstruction images to simulate the antemortem dental radiographic images for dental radiographic comparison. Notably, this Queensland case series is the first to demonstrate the comparison of non-dental antemortem radiographs to MPR images derived from PMCT data to achieve a dental identification outcome. The utility of PMCT MPR dental images in personal forensic dental identification has been demonstrated in the literature.[16]
Many countries do not have a centralised dental records repository, hence it can be a challenge to source and collect antemortem dental records, especially if there is no lead or indication of the potential resources.[17] Some countries, like Australia, have several private radiology centres. Forensic odontologists (with approval from the Coroner or Medical Examiner) can search within these radiology centres' central image repositories for any potential antemortem dental and medical radiographic images which could be used for forensic dental identification. With the Queensland Coroner's permission, FPaCS forensic odontologists are able to access the radiology repositories of private radiology centres and Queensland Health (government) facilities to locate the person's medical or dental radiographic images. The availability of the radiographic images in digital format is useful, as they can be easily retrieved and transmitted, whilst maintaining their quality. If digital radiographic images are not available, the forensic odontologist can liaise and guide the police to assist with retrieving antemortem hardcopy film data. Antemortem data collection is a team effort.
This case series from Queensland highlights the importance of forensic teamwork and looking outside the norm of antemortem dental data collection to achieve an outcome in forensic dental identification.

CONCLUSION

Forensic dental identification regularly uses antemortem dental radiographs, such as orthopantomogram (OPG), dental cone beam computed tomography (CBCT), bitewing, and periapical (PA) views, for comparison with postmortem dental radiographs. However, as demonstrated in this article, forensic odontologists have to be aware of non-dental radiographs that could potentially have captured the oral and dental features of the person, such as medical radiographs of the head and neck region. This Queensland case series demonstrates the usefulness of antemortem non-dental radiographic images for forensic dental comparison, notably being the first to highlight their comparison to MPR images produced from PMCT data. This article also highlights the importance of collaboration within the forensic team which includes forensic odontologists, forensic pathologists, police, and coroners. Effective collaboration allows the location and collection of the antemortem data necessary to achieve an identification of the deceased person.

ETHICS APPROVAL

Authorisation provided by the State Coroner, Chief Forensic Pathologist, and Coronial and Public Health Sciences - Human Ethics Committee.

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Integration of forensic odontology services at the National Institute of Forensic Pathology “Doctor Sergio Sarita Valdez” (Dominican Republic): a report of procedures from 2000 to 2024

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The authors declare that they have no conflict of interest.

KEYWORDS

Forensic service, Forensic odontology, Violent deaths, Natural deaths, Medico-legal autopsy, Dominican Republic

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ABSTRACT

Forensic odontology (FO) is grounded in a well-established historical framework, necessitating adherence to minimum standards to ensure quality on an international scale. Nonetheless, these standards frequently fail to account for the considerable variability in challenges, resources, and practices at the national or local levels. The Dominican Republic, the second-largest nation by area after Cuba in the Antilles and the second-largest by population after Haiti, has exhibited one of the highest economic growth rates in Latin America and the Caribbean. However, it also faces complexities and challenges due to population movement and rising crime rates. The enactment of new legislation and the establishment of institutions, such as the National Institute of Forensic Pathology “Doctor Sergio Sarita Valdez” (INPFSS), signify their contributions to the advancement and modernization of the Judiciary and Public Health through service, education, and forensic research. This article presents the work undertaken by the FO department during autopsies conducted at the INPFSS between 2000 and 2024, highlighting the strengths, weaknesses, and opportunities for improvement that the service has identified as challenges, striving to align with global standards while consistently considering local realities and resources. We assert that the FO procedures at the INPFSS are distinctive, at least within the Latin American context, as they genuinely contribute to illustrating not only current practices but also potential enhancements aimed at advancing Dominican forensic work in accordance with global standards.

INTRODUCTION

Forensic odontology (FO), the application of dental science within the legal domain, encompasses several distinct areas: the identification of unidentified remains, bite mark analysis, the interpretation of oral injuries, and dental malpractice.[1] FO possesses a robust historical foundation, exemplified by the International Organization for Forensic Odonto-Stomatology (I.O.F.O.S.), a global entity that fosters goodwill, advancement, and research,[2] and promotes international recognition of FO as a "primary identifier" among the most reliable methods for confirming identity.[3] Nevertheless, while FO procedures should adhere to a minimum standard to ensure quality at an international level, these standards often fail to accommodate the significant variability in problems, resources, and practices at national or local levels.[4] Solheim (2018) asserts that due to the differences among countries in defining FO, its essential knowledge, and the scope of its field procedures, it is extremely difficult to reach consensus on technical requirements or even on the minimum qualifications for its professionals and expert reports.[5]

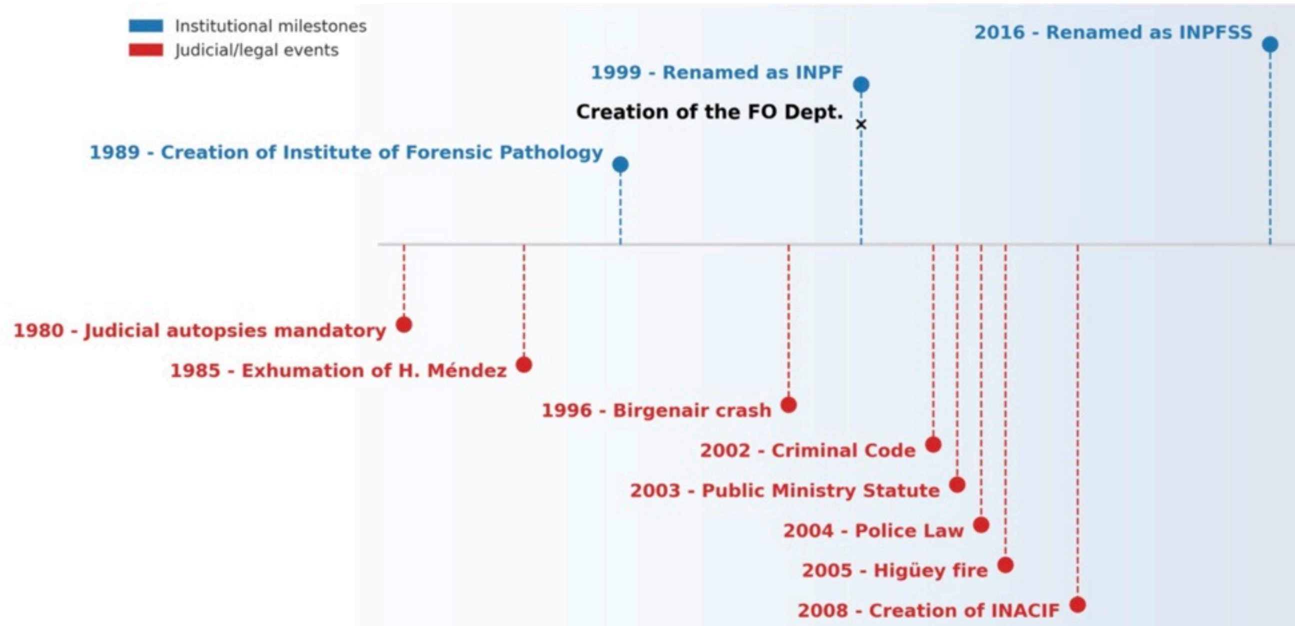
The Dominican Republic, situated on the island of Hispaniola within the Greater Antilles of the Caribbean Sea, shares a maritime boundary with Puerto Rico to the east and a land boundary with Haiti to the west, occupying the eastern five-eighths of the island. It ranks as the second-largest nation by area after Cuba in the Antilles and the second-largest by population after Haiti, exhibiting one of the highest economic growth rates in Latin America and the Caribbean.[6] As the most frequented tourist destination in the Caribbean, coupled with its population density and both regular and irregular migration phenomena, the country faces specific challenges necessitating intricate medico-legal strategies.[7] The notable rise in crime, the lack of reliable records, and the sluggishness of criminal proceedings in the courts prompted a series of systemic reforms in the early 2000s, aimed at delivering timely responses despite the limited resources available at that time.[8] The implementation of the Dominican Republic's Criminal Procedure Code in 2002,[9] the approval of the Statute of its Public Ministry in 2003,[10] the enactment of the Institutional Law of the National Police in 2004,[11] and the establishment of the National Institute of Forensic Sciences of the Dominican Republic (INACIF) in 2004 (later formalized by law in 2008[12] collectively signify the substantial transformation experienced by the Dominican criminal justice system. These reforms sought to reduce judicial backlog and bureaucratization, expedite processes, redefine the roles of the actors, and delineate the functions of investigation.[8]

Although Dominican forensic medicine possesses a significant historical foundation,[13] it was not until the implementation of mandatory judicial autopsies in 1980[14] that the formal guidelines for the procedure were clarified, highlighting the necessity for both the procedure itself and the presence of trained forensic pathologists.[15] It has been posited that cases of national importance, such as the murder of currency exchange trader Héctor Méndez in 1985, which necessitated exhumation for further forensic evaluation, underscored the importance of an agency dedicated to such services.[16] In 1989, the Institute of Forensic Pathology *(Instituto de Patología Forense)* was established under the jurisdiction of the Attorney General's Office to conduct judicial autopsies.[17] This institution was renamed the National Institute of Forensic Pathology (INPF) in 1999, reflecting its contributions to the advancement and modernization of the Judiciary and Public Health through service, education, and forensic research.[18] The establishment of INACIF in 2008 introduced new responsibilities for the INPF, although it continued to perform autopsies.[19] In 2016, the INPF was renamed the National Institute of Forensic Pathology "Doctor Sergio Sarita Valdez" (INPFSS) in recognition of the esteemed training, reputation, and contributions of this distinguished Dominican professional and academic.[20] Since that year, the INPFSS has redirected its focus towards conducting autopsies of natural deaths, although it also occasionally supported autopsies of violent deaths or other tasks together with the INACIF.

On February 6, 1996, the crash of Birgenair Flight 301 in Puerto Plata, a municipality in the north of the Dominican Republic, resulted in the tragic loss of 189 lives, predominantly German tourists returning home.[21] This incident also highlighted the absence of Dominican forensic odontologists in the identification process of the victims. Dr. Sergio Sarita Valdez, then director of the INPF, advocated for the integration of these specialists into a dedicated FO department at the institute, which was realized in 1999 (Fig. 1).

This department has been in continuous operation up to the present INPFSS, making significant contributions to public events, such as the fire during a riot at the Higüey prison, which resulted in 133 fatalities.[22] The role of forensic odontologists at the INPFSS has been well-documented, as they participate not only in victim identification but also collaborate in all autopsies during the external examination, thereby enhancing the detection of intraoral evidence.[7] The current staff composition of the INPFSS comprises one director, one deputy director, five coroners, three histopathologists, one pediatrician, two gynecologists, three laboratory technicians, three autopsy room technicians, and five forensic odontologists. Additionally, medical students specializing in forensic pathology engage as residents at the institute throughout their four-year training period. Each autopsy conducted at the INPFSS, irrespective of whether the cause of death was natural or violent, involved the participation of one coroner, one histopathologist, one forensic odontologist, one fourth-year resident, one third-year resident, two second-year residents, three to four first-year residents, and one autopsy technician. Significantly, a forensic odontologist participated in all autopsies, suggesting that, in addition to conducting specific odonto-stomatological procedures, their involvement facilitates the oversight of the autopsy process as a quality assurance measure. This approach helps prevent the underestimation or omission of oral information pertinent to the determination of the cause of death. The primary aim of this study was to elucidate the work conducted by forensic odontologists during autopsies performed at the INPFSS between 2000 and 2024. It emphasizes the strengths, weaknesses, and opportunities for enhancement that the service has identified as challenges, striving to align with global standards while consistently considering local realities and resources.

Figure 1. An infographic featuring a timeline that encompasses both institutional milestones and significant judicial or legal events within the country. Note the establishment of the FO department in 1999.



MATERIALS AND METHOD

This study conducted a retrospective analysis of all autopsy reports completed at the INPFSS from 2000 to 2024, with particular emphasis on the procedures performed by forensic odontologists during these examinations. Given that the responsibility for conducting autopsies and involving forensic odontologists in these procedures has consistently resided with the institution under examination, this retrospective analysis generically refers to the institution as the "INPFSS". This designation will be maintained throughout the study period from 2000 to 2024, irrespective of any changes to the institution's name, to prevent confusion. Data were systematically recorded using Microsoft Office Excel, and descriptive statistics were presented as numbers (n) and percentages (%). FO procedures were classified into distinct categories based on the US National Academy of Sciences report,[1] with specific modifications: "dental identification" (D-ID), "dental age estimation" (DAE), "bite mark comparison" (BMC), "interpretation of oral injuries" (IOI), "dental malpractice" (DMP), and "miscellaneous" (MISC) (tasks not encompassed by the aforementioned categories). To facilitate data interpretation, each FO procedure was assigned to only one category, specifically the most significant one.

RESULTS

Table 1 presents data on 43,044 autopsies conducted at the INPFSS from 2000 to 2024, with an annual average of 1,721. The year 2003 recorded the highest number of autopsies (2,527), while 2020 recorded the lowest (969).

Despite the absence of records for the years 2000, 2001, 2003, and 2004, a predominance of autopsies for violent deaths over natural deaths was evident until 2015, peaking between 2009 and 2011. This trend reversed in 2016, following the reassignment of roles to the INACIF in accordance with local regulations.

Table 1. General and FO procedures for autopsies conducted at the INPFSS from 2000 to 2024

yrs.	Autopsies			FO procedures							
	Violent deaths	Natural deaths	Total	D-ID	DAE	BMC	IOI	DMP	MISC	Total FO procedures	(%)**
2000	*	*	1850	10			25			35	(1.89)
2001	*	*	1929	5			8			13	(0.67)
2002	1665	470	2135	8	90		12			110	(5.15)
2003	*	*	2527	15	89		25			129	(5.10)
2004	*	*	2253	7			50			57	(2.53)
2005	1247	372	1619	39	113		8			160	(9.88)
2006	1149	428	1577	5	87	1	19			112	(7.10)
2007	1112	464	1576	6	99	3	76		1	185	(11.74)
2008	1234	451	1685	4	205	1	73		7	290	(17.21)
2009	1658	0	1658	3	59	3	10	1	9	85	(5.13)
2010	2038	0	2038	1	29		35		3	68	(3.34)
2011	2263	0	2263	4	118		16			138	(6.10)
2012	1478	97	1575	2	93		25		4	124	(7.87)
2013	824	941	1765		56	3	24		5	88	(4.99)
2014	895	851	1746		31		21		1	53	(3.04)
2015	967	897	1864	2	35		25		4	66	(3.54)
2016	167	1211	1378		10		17	1		28	(1.50)
2017	45	1256	1301	1	2		8		6	17	(1.31)
2018	40	1486	1526		37		3	1	4	45	(2.95)
2019	53	1574	1627		30		4	1	4	39	(2.40)
2020	37	932	969	1	15		6		4	26	(2.68)
2021	68	1226	1294	3	15		7		4	29	(2.24)
2022	71	1238	1309	4	9	2	6		3	24	(1.83)
2023	59	1673	1732		27		8	1	3	39	(2.25)
2024	5	1843	1848	2	6		8			16	(0.87)
		TOTAL	**43,044**	**122**	**1,255**	**13**	**519**	**5**	**62**	**1,976**	**(4.59)**

Notably, INPFSS policies mandate the presence of at least one forensic odontologist at all autopsies conducted at the institute. A total of 1,976 FO procedures, significant for autopsy work, were reported, constituting 4.59% of all autopsies performed. The year 2001 recorded the fewest procedures (13 FO procedures, 0.67% of the total for that year), while 2008 recorded the

most (290 FO procedures, 17.21% of the total for that year), with an average of 79 FO procedures per year.
Table 1 also details the distribution of D-ID, DAE, BMC, IOI, DMP evaluations and MISC throughout the study period. The most frequent FO procedures were DAEs, totaling 1,255 procedures (63.51% of the total FO procedures), with a peak of 205 procedures in 2008 and an average of 50 DAE procedures annually. According to the INPFSS protocol, every unidentified body entering the autopsy undergoes a DAE for record purposes, irrespective of the cause of death or subsequent identification by other means, accounting for the high number of DAE procedures recorded. The second most frequent FO procedure was IOI, with 519 procedures (26.27% of total FO procedures), peaking at 76 procedures in 2007 and averaging 21 IOI procedures annually. It is important to note that the oral injuries assessed by forensic odontologists in this category pertain solely to the cause of death, excluding incidental injuries, which are categorized as MISC.
The third most prevalent FO procedure was D-ID, accounting for 122 procedures (6.17% of the total FO procedures). The majority of these involved the identification of individual cases. A notable peak of 39 D-IDs occurred in 2005, with 30 related to the aforementioned fire during a riot at Higüey prison,[22] and an average of five cases per year. Although not included in these results due to their primary assignment to the INPFSS, the FO department collaborated with the INACIF on D-ID tasks in different media-significant incidents involving multiple victims.[23-25] Concerning BMC procedures, the FO department reported conducting 13 procedures within forensic autopsy contexts, in addition to four BMC procedures on living subjects (not included in the table), in contexts of interpersonal violence and/or child abuse (three in 2009 and one in 2016). Regarding the evaluation of individuals who died from suspected DMP, the FO department reported conducting five procedures: three for Ludwig's angina (2009, 2016, and 2019), one for peritonsillar abscess (2018), and one for pharmacological idiosyncrasy (2023), all resulting from failed dental treatments.
The MISC category (Table 2) encompassed all FO procedures not included in the other categories and was the fourth most common procedure performed by INPFSS forensic odontologists, with 62 procedures (3.13% of the total and an average of 2.5 per year). Among these MISC procedures and during medico-legal autopsies, 23 instances of FO detection and/or evaluation of intraoral foreign materials were noteworthy. Of these, 16 cases were associated with choking and identified as the direct cause of death, predominantly involving “cafe coronary syndrome”. The term "Cafe coronary syndrome," also known as "bolus death," refers to a relatively common occurrence of asphyxia resulting from the obstruction of the upper airways by food. In such cases, an autopsy oral examination is recommended to accurately determine the cause of death.[26] Additionally, there were 7 cases in which foreign materials were incidentally discovered intraorally, which did not directly cause death but were documented as items such as a coin, a bullet, or a package containing drugs. In the context of autopsies related to natural deaths, the recording of 23 cases of incidental oral diseases, which encompass malformative, inflammatory, or infectious conditions associated with the natural cause of death, is significant. Additionally, there were nine further records of Ludwig's angina that were not reported as DMP claims and four instances of oral cancer features. Notably, the participation of INPFSS odontologists in three autopsies for intraoral examination, which subsequently resulted in a COVID-19 diagnosis, underscores adherence to the protocol requiring the involvement of forensic odontologists in all autopsies. This protocol was upheld even during the health crisis owing to the absence of a certified cause of death at the time of the procedure.

Table 2. Annual distribution of MISC procedures.

yrs.	Intraoral foreign materials*	Incidental oral diseases	Ludwig's angina**	Oral cancer	COVID-19	Total
2007	1					**1**
2008	3	2	2			**7**
2009	9					**9**

2010	3					**3**
2011						
2012	2	2				**4**
2013	3	2				**5**
2014	1					**1**
2015	1	2		1		**4**
2016						
2017		5		1		**6**
2018		3		1		**4**
2019		3	1			**4**
2020			2		2	**4**
2021		1	1	1	1	**4**
2022		1	2			**3**
2023		2	1			**3**
2024						
TOTAL	23	23	9	4	3	**62**

DISCUSSION

While there is a general consensus on the definition of forensic odontology and its primary areas of focus, such as identification,[1] it is important to admit, as Solheim has noted, the significant heterogeneity in these concepts across different countries, despite efforts to standardize them.[5] The Dominican system has endeavored to adapt its resources to local needs, striving to "do more with less"[27] given that Central America and the Caribbean are regions where violence is endemic, and there are substantial social, political, and economic challenges.[28] In 2023, the INPFSS conducted 1,732 autopsies on individuals from 51 different countries. This statistic underscores the significant demands placed on Dominican forensic services, which are exacerbated by the substantial influx of tourists and illegal migrants, as previously mentioned in this study. These circumstances necessitate diplomatic procedures for document management. Pachar Lucio asserts that the advancement of forensic institutions is hindered by a lack of official support, inadequate state budget allocations, and, with few exceptions, the absence of specialized forensic professional training and the acquisition or application of modern technologies.[28] From a FO perspective, it has been observed that Latin America has sufficient local issues to address without importing foreign problems and solutions.[29] Consequently, the Dominican Republic, far from seeing the situation on a positive side of things, "a glass half full" situation, and "despite more than forty years of dedicated efforts," still views itself as "far from guaranteeing basic forensic services." These words were spoken in June 2025 by Dr. Sarita Valdez, whose name is honored by the INPFSS.[30]

However, this report of the FO procedures carried out at the INPFSS highlights a distinctive quality over other services: the participation of a forensic odontologist in all autopsies, thereby enhancing the recovery of evidence and assisting the coroner in making diagnoses during external examination. This has rarely been reported, and is almost an anomaly in the functioning of systems globally. This report illustrates that a primary responsibility of the FO department is the implementation of internal protocols for DAE on all unidentified bodies undergoing autopsy. Given that every unidentified corpse undergoing autopsy is subjected to DAE for registration purposes, the opportunity to obtain potentially identifying information—even before antemortem data can be found—is a distinct advantage made possible by the presence of a forensic odontologist working alongside the coroner during all autopsies. The 1,255 DAE procedures conducted during the study period reflect a noteworthy institutional decision, aligning with contemporary trends in FO research.[31] Moreover, the noted population heterogeneity, influenced by external factors, poses challenges to the global and multicenter validation of DAE methods, an area in which the FO department has already achieved considerable advancements.[32]

It has already been mentioned that there are few reports, research, and publications dedicated to the study of oral signs in medico-legal autopsy contexts, either due to the absence of individuals trained in their interpretation or due to the real lack of interdisciplinary procedures, which could mean that forensic odontology "is underestimated, and its role in the analysis of oral signs during all medico-legal autopsies is not currently considered".[33] Since 2016, the responsibilities of INPFSS forensic odontologists have increasingly encompassed the performance of autopsies for natural deaths, although not exclusively. This transition has facilitated the identification of new competencies and roles, particularly in the collection of oral evidence that would otherwise remain inaccessible. To the best of our knowledge, forensic odontologists are not typically involved in the detection, evaluation, or analysis of intraoral foreign materials during medico-legal autopsies. However, they could initially assume this role during the external examination of the corpse, with the material still in situ, to obtain potentially significant information for the investigation, even in instances where the material may not have been the direct cause of death. This report specifically highlights the 23 procedures in which these intraoral foreign materials were evaluated by the FO department of the INPFSS, in accordance with recommendations in the literature[34,35] to ensure the requisite quality of autopsy procedures.[36] We propose that this line of work be explored in greater depth through formal research in the future.

In the realm of medico-legal autopsies, the IOI aligns with the evolving role of the forensic odontologist, as previously advocated in the literature.[33] The INPFSS further extends this emphasis by highlighting the significance of this role in autopsies for natural deaths conducted at the institution. Table 2 presents the various FO involvements of the INPFSS in documenting oral diseases, which in some instances were incidental, while in others were crucial for establishing or confirming neoplastic diagnostic conditions (tongue cancer in 2015, larynx in 2017, hard palate in 2018, and cheek in 2021). Additionally, in 2018, the FO department conducted a postmortem evaluation of a fatal case of peritonsillar abscess, and between 2008 and 2023, forensic odontologists assessed 12 fatal cases of Ludwig's angina, three of which were attributed to reports of dental negligence. In 2023, the FO department also evaluated a fatal case of pharmacological idiosyncrasy, reported as dental malpractice, following the administration of anesthetics for third molar extraction in a 19-year-old victim. It is well recognized that all these conditions can originate from dental care and are considered rare in contemporary forensic reports.[37-39] While these cases acknowledge potential dental origins, necessitating further investigation into the decedent's clinical history prior to death,[40-42] autopsy reports involving odontologists remain exceedingly rare.[43]

Unfortunately, it is impossible to ignore local, financial, and even political circumstances that can affect both the structure and functioning of the INPFSS,[19] elements that have already been mentioned as determining factors for the stability of any forensic system.[27] Undoubtedly, the indistinct boundaries between the INPFSS's autopsies of natural and violent deaths, as well as the potential overlapping functions between the INPFSS and the INACIF, may result in confusion or complicate the comparison of these data with those provided by other services in Latin America or globally; however, the medico-legal autopsy may also be required in cases of non-violent deaths but with relevance due to the illicit or negligent conduct of third parties and that, obeying the current regulations of the country in question, the techniques must ultimately be adapted to the local needs of their forensic pathologists.[44] It is essential to underscore the significance of conducting a thorough external examination by systematically documenting any form of injury or abrasion prior to undertaking the internal examination. Furthermore, an interdisciplinary approach should be deemed obligatory in all autopsy procedures.[44] The inclusion of forensic odontologists in all INPFSS autopsies has been shown not only to complement the coroner's report of the cause and mechanism of death but also to contribute to enhancing communication between forensic experts and pathologists and thus to improving the quality of autopsies and their reports, in line with the emphatic suggestions made by the literature.[36,45] The involvement of forensic odontologists during the external examination of autopsies may be crucial for several reasons: they can inspect intraoral characteristics that might indicate the cause of death, evaluate the intraoral presence of foreign materials, irrespective of their role in causing death, identify and evaluate the fit of dislodged dental devices and their role in any oral injuries, and verify the original position of a dislodged tooth along with the likely reason for its detachment, such as blunt force, intubation, or an existing pathological issue. Additionally, they can determine the type of missing tooth when only a bloody socket is visible, aiding investigators at the scene in differentiating intraoral trauma and sometimes assisting in reconstructing the events leading to the trauma. They also identified incidental oral pathologies (as seen in this report), which could be valuable in establishing identity, determining antemortem clinical behavior, or simply providing a complete evaluation in any type of autopsy. As highlighted, the responsibilities of a forensic odontologist during a medico-legal autopsy should extend beyond merely identifying an unknown individual. They should also include assessing any morphological features of the oral cavity, both internal and external, that could shed light on the cause of death.[33,35]

Since 2000, the FO Department of the INPFSS has been involved in all autopsies conducted at its facilities. It is essential to recognize the department's additional significant contributions to the Dominican system, which, although not detailed in this report, are of great importance. Upon the request of the prosecutor's office, the FO Department routinely conducts assessments of living individuals for DAE procedures in various penal cases and evaluates bite mark evidence in instances of child abuse, mistreatment, and domestic violence. Furthermore, the INPFSS and the INACIF have collaborated on numerous victim identification cases that have garnered substantial media attention.[23-25] Given the Caribbean's distinctive population history, and the numerous archaeological sites in the Dominican Republic, dental anthropology work has also been addressed by INPFSS forensic odontologists.[46-48] In terms of research, the FO department has engaged in various projects focused on DAE, either as part of multicenter studies,[32] or by validating them in Dominican populations,[49] as well as in redefining forensic dental work during medico-legal autopsies.[7,50] The FO department currently offers regular instruction in both undergraduate and graduate programs in the disciplines of dentistry and law across several institutions, with both national and international reach.[51] Additionally, it maintains a robust relationship with the media [52,53] and recognized scientific societies. In 2024, in response to the evident need to enhance the facilities of the INPFSS to accommodate this demanding repositioning, the remodeling and expansion of the Institute were inaugurated with the aim of modernizing and facilitating the study and delivery of corpses.[54]

This report highlights both achievements and challenges. It has been noted that Latin American FO is often characterized by complexity, self-sufficiency (in the less favorable sense), and isolation from global standards.[29] However, it is also recognized for its significant progress, pursuit of international collaboration, and promotion of quality assurance in its protocols and evaluations.[55] The I.O.F.O.S. asserts that “quality assurance should never be static”, emphasizing that staying updated with scientific advances and practices can address “the huge variability of approaches at the international level or the differences of caseworks in these wide fields of forensic odontology”.[4] We consider this report on 25 years of FO procedures at the INPFSS to be unique, at least within the Latin American context, as it genuinely contributes to demonstrating not only current practices but also potential improvements aimed at enhancing Dominican forensic work “to promote goodwill, advancement, and research in forensic odontology”.[2]

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