University of Nevada, Reno

Exploring the Utility of Dental Pathological Conditions in Dental Radiographic Comparisons

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Anthropology

by

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THE GRADUATE SCHOOL

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Abstract

Dental forensic identifications can be achieved through comparative dental analysis (CDA) by comparing a decedent's postmortem (PM) dental records to a suspected match's antemortem (AM) dental records. Dental records are particularly useful for CDA, because the number of concordant dental identifiers (DI) and the presence of discrepancies present in a dental radiograph has a demonstrated impact on forensic practitioners' ability to interpret dental radiographs for positive identification. However, few studies have tested how matching accuracy is influenced by individuals' experience and expertise in conjunction with testing the utility of pathological dental identifiers. Therefore, in this study, a survey questionnaire was designed 1) to test if the presence/absence of dental pathological conditions and dental restorations would lead to more correct matches when CDAs are conducted in medicolegal death investigation (MDI), 2) to determine if respondents' expertise and experience would affect their ability to make correct matches, and 3) to investigate which DI were most/least beneficial in making correct matches. To test these hypotheses, 60 decedents' dental radiographs (i.e., one antemortem and one post-mortem) were collected from the Washoe County Regional Medical Examiner's Office (WCRMEO) and compiled into a questionnaire survey. The questionnaire survey was administered on Qualtrics XM Software to a sample of respondents (N=6) with known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology. The sixty arrays were divided into four sections by match/non-match and presence/absence of dental restorations and/or pathological conditions. Results from this study suggest that the presence of DI has a notable effect on match accuracy rates, particularly when radiographs are of the same

individual; although, the non-match category with pathological conditions had a higher accuracy rate than the arrays without pathological conditions, even though the difference was small. In addition, no respondents achieved a perfect score in the questionnaire survey, and there no differences among respondents groups. These results indicate that people with known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology may be able to make correct matches in CDA; however, comparative literature suggests that only people with dental qualifications and experience should conduct CDAs in MDI.

KEYWORDS
Antemortem and postmortem comparisons, Competency, Dental identifiers, Dental radiography, Forensic odontology, Identification match accuracy

List of Abbreviations

Abbreviations	Definitions
AM	Antemortem
CDA	Comparative Dental Analysis
DI	Dental Identifier
FO	Forensic Odontologist
MDI	Medicolegal Death Investigation
PDI	Pathological Dental Identifiers
PM	Postmortem
RDIDP	Restorative Dental Identifiers Associated with Dental Pathology
WCRMEO	Washoe Country Regional Medical Examiner's Office

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INTRODUCTION

Comparative Dental Analysis

Dental evidence is invaluable for human identification in MDI (see American Dental Association Standards Committee on Dental Informatics ADA SCDI 2020; ASB Standard 148 2023). Teeth are primary identifiers (i.e., individualizing features) in a forensic context that can assist forensic investigators in making probable identifications of a decedent (ASB Standard 148 2023; Carabott 2013; Gorza and Mânica 2018; Yazdanian et al., 2022). According to Gorza and Mânica (2018: pg 337), dental records are invaluable tools for MDIs because, "The pattern and combination of dental treatments, anatomic and pathologic features are hardly similar between different subjects". That is that teeth are unique to themselves and dental records are most effective for visual comparisons. Visual comparison of dental records (i.e., CDA) is ideal for dental identification, because visual comparison is inexpensive and the most common method for analysis of dental films and radiographs (Gorza and Mânica 2018; Kahana and Hiss 1997). In addition, Yazdanian and colleagues (2022) note that the likelihood of a positive identification in an MDI is improved by the development and implementation of forensic odontological analyses, such as CDA.

A positive identification can be achieved through CDA by comparing a decedent's PM dental records (i.e., data compiled throughout the autopsy) to a suspected match's AM dental records (i.e., intra-oral and extra-oral dental radiographs and dental medical records taken during life) (Carabott 2013; Forrest 2019; Gorza and Mânica 2018). When CDAs are conducted, the forensic odontologist (FO) will distinguish unique dental features from normal radiographic anatomy to distinguish and positively identify decedents (see Thomson and Johnson 2018). More specifically, CDA is based on the

comparison of DI related to: dental pathology, restorative dental treatment, dental morphology, or a combination of these DI (Angelakopoulos et al., 2017; Picoli et al., 2019; Scott and Pilloud 2018; Senn and Weems 2021; Tinoco et al., 2010).

Dental Identifiers

When CDAs are conducted, the FO will distinguish unique dental features (i.e., dental identifiers [DI]), from normal radiographic anatomy (see Thomson and Johnson 2018). According to the ASB Standard 148 (2023), DIs (e.g., dental restorations/ pathology, anomalies, trauma) are classified as 'Potentially Individualizing Features'. Potentially Individualizing Features are defined by the Anthropology Consensus Body, ASB Standard 148 (2023: pg 4) as "skeletal or dental characteristics that may assist with the identification of the individual should antemortem records and/or imaging become available that can support an inclusion or exclusion of a potential identification". For example, when a FO conducts a CDA, they evaluate a decedent's DI, as teeth are unique to themselves and the presence/absence of these identifiers can be used as corroborative evidence to make a positive identification (Angelakopoulos et al., 2017; Rai and Kaur 2013; Yazdanian et al., 2022). In this context, a FO's knowledge of dental anatomy, including its variants, are vital for human identification in a MDI, because the degree of identification certainty is dependent on the presence/absence of DI found in the decedent's dental records and the degree of expression in which a DI presents (ABFO 2020; Pereira and Santos 2013; Yazdanian et al., 2022).

For instance, FOs often utilize the standards defined in the International Organization for Forensic Odonto-Stomatology [IOFOS] to determine the degree of identification certainty (ABFO 2020; Pereira and Santos 2013). The IOFOS defines four

levels of certainty: 1) Identity established- there is ample AM and PM data with several definite identical characteristics and discrepancies are compatible with time discrepancies between AM and PM documents (i.e., Nothing refutes identity), 2) Identity probable- there is limited AM and PM data with at least one identical characteristic and discrepancies are compatible with time discrepancies between AM and PM documents (i.e., Nothing refutes identity), 3) Identity possible- there is limited AM and PM data with no identical characteristic and discrepancies are compatible with time discrepancies between AM and PM documents (i.e., Identity cannot be excluded), and 4) Identity excluded- at least one identical characteristic refutes identity confirmation (ADA SCDI 2020).

Likewise, the ABFO's *Diplomates Reference Manual, Section VI: Appendix* (2020) has established categories to describe the levels of certainty for a dental identification in an MDI. The categories include: 1) Positive Identification- AM and PM data are concordant with no notable discrepancies, 2) Possible Identification- AM and PM have consistent dental feature, but the AM and PM data quality cannot be used to confirm dental identification, 3) Insufficient Evidence- available AM and PM data are insufficient for dental identification, and 4) Exclusion- AM and PM data incompatible (ABFO 2020; ADA SCDI 2020).

In essence, the key to successfully interpreting a CDA appears to be based upon the degree to which DI are present/absent and the quality of the dental radiographs available. For this reason, this project aims to analyze how respondents utilized the presence/absence of DI to compare dental arrays. Specifically, this project opted to analyze those DI that occurred due to pathological and restorative intervention, because:

1) they are radiographically and skeletally observable (see Bradshaw et al., 2022), and 2) have historically improved the rate of human identification when comparing arrays in a survey questionnaire (ABFO 2020; Pereira and Santos 2013; Wood 2006).

Dental evidence is clearly invaluable to MDIs, because the presence/absence of DIs can be quantified to determine the degree of identification certainty (ABFO 2020; Pereira and Santos 2013). In addition, Bradshaw and colleagues (2022) note that the prevalence of DIs increases during an individual's lifespan. Therefore, it stands to reason, if obvious (easily identifiable) dental restorations and/or pathological conditions can be identified in dental records, then the probability of an individual making positive matches in a CDA should improve. However, there are no standardized protocols for conducting these analyses (Gorza and Mânica 2018; Pinchi et al, 2012). Furthermore, the final determination of a CDA is largely determined by the analyst's personal interpretation, and identity may be confirmed or excluded on the basis of a single dental trait. For example, Pinchi and colleagues (2012: pg 252) state, "the operator's subjective judgment can considerably affect identification".

Previous studies tested the matching accuracy of individuals with different levels of experience and expertise by conducting CDA of dental radiographs (Bradshaw et al., 2022; Gorza and Mânica 2018; Page et al., 2018; Pinchi et al., 2012; Wenzel, Richards, and Heidmann 2010). In addition, previous studies tested the utility of dental identifiers and their effect on matching accuracy when CDA of dental radiographs were conducted (Bradshaw et al., 2022; Gorza and Mânica 2018). Notably, few studies have tested the matching accuracy of individuals with different levels of experience and expertise, in

conjunction with testing the utility of dental identifiers and their effect on matching accuracy, when CDA of dental radiographs are conducted.

Therefore, in this study, a survey questionnaire was designed to explore which factors (i.e., respondents' expertise/experience and the utility of dental identifiers) influence the ability to make a correct match in a CDA. The hypothesis of this study is that the presence of pathological conditions and dental restorations in the oral cavity will lead to more correct matches. However, for the sake of this small and targeted study, the goal was not to validate (i.e., positively identify the decedents); rather, to identify if and which DI were helpful in making an identification.

The first aim of the research was to test if the presence/absence of dental pathological conditions and dental restorations would lead to more correct matches when CDAs are conducted in a MDI. The second aim of the research was to determine if respondents' expertise (i.e., degree and board certification) and experience (i.e., experience in handling forensic cases and dental radiographic comparisons, total years practicing in MDI) would affect their ability to make correct matches. The third aim of the research was to investigate which DIs were most/least beneficial in making correct matches.

Dental Identifiers: Terminology

Dental Identifiers, Terminology: Dental Pathological Conditions

According to ASB Standard 148 (2023), a pathological condition is a "skeletal abnormality resulting from disease processes" (1). In a dental context, oral pathology is described in a similar manner. For instance, the *Medical Dictionary for the Dental Professions* (2012) defines oral pathology as a "Branch of dental science dealing [with] study, diagnosis, and causes of oral disease and the changes they produce". For the

purposes of this study, pathological conditions of the dentition were identified as: dental caries, periodontal disease, and periapical lesions (see Pilloud and Fancher 2019). These are pathological conditions of the oral cavity as they are documented maladies of the dentition, maxilla, and mandible (skeletal elements of the oral cavity) that occur due to the degradation of these skeletal structures' integrity (Nelson 2015; Pilloud and Fancher 2019; Slootweg 2013).

In this study, dental pathological conditions were observed in a skeletal context, because oral health (e.g., dental diseases) can be quantified by analyzing a multitude of skeletal indicators (e.g., a radiographic signature on the bone, the presence/absence of the pathology) (Pilloud and Fancher 2019). However, Pilloud and Fancher (2019) note that formal diagnoses of dental diseases in a bioarchaeological sample (i.e., a skeletal context) is difficult to assess, because researchers often do not have access to clinical records and documented patient history records. Therefore, in order for a pathological condition of the dentition to be considered a DI within a skeletal context, 1) a pathological condition must have manifested in the oral cavity and have left a pathological signature on the skeletal elements of the oral cavity, and 2) the pathological condition must be radiographically observable. For the purposes of this study, pathological conditions of the dentition, unless otherwise noted, will henceforth be referred to as pathological dental identifiers (PDI).

Dental Identifiers, Terminology: Restorative dental identifiers associated with dental pathology

Wood (2006) states, "Radiographic records provide objective evidence of the anatomical conditions and the dental treatment provided up to the point in time. Most cases of comparative identification use radiographic evidence of dental intervention

(restorations, root fillings, crowns, extractions, etcetera) as common points of identification." (S48). In acknowledgement of Wood's statement and to provide a comprehensive view of how dental pathological conditions manifest in the oral cavity (i.e., presence of a pathological condition and the potential subsequent dental treatment provided), the researchers determined that "dental intervention" (i.e., dental restorative treatment) associated with dental pathological conditions would also be considered a PDI in this study. However, for the sake of clarity, restorative dental identifiers associated with PDI, will be referred to as, 'restorative dental identifiers associated with dental pathology' (RDIDP), unless otherwise noted.

For the purposes of this study, a restorative treatment associated with a pathological condition of the dentition was identified as: fillings, crowns, bridges, implants, root canal therapy, and orthodontic appliances. These restorative treatments are associated with pathological conditions of the dentition, because they are documented dental restorative treatments for dental maladies (see Thomson and Johnson 2018). In a skeletal context, in order for restorative treatments to be considered RDIDP, 1) the restorative treatment must be present on the skeletal elements of the oral cavity, and 2) the restorative treatment must be radiographically observable. These criteria were selected for identifying RDIDP in this study, because oral health can be quantified by analyzing skeletal indicators (see Pilloud and Fancher 2019). Therefore, if restorative treatment is skeletally indicated (i.e., restorative identifiers are present in the oral cavity) and radiographically observable (see Iannucci and Howerton 2021; Thomson and Johnson 2018), there is sufficient skeletal evidence of restorative treatment to be considered a RDIDP in this study.

Proof of pathological manifestation was not necessary for dental restorative identifiers to be considered a RDIDP in this study, because the intent of restorative treatment varies (i.e., restorative intervention or aesthetic alteration). For instance, dental restorative treatment is frequently conducted for aesthetic purposes (i.e., discoloration, straightening the teeth, or to fill the space where a tooth is congenitally absent) (see Academy of General Dentistry [AGD] 2012; Healthdirect Australia 2021). Consequently, the intent of restorative treatment is largely indeterminate when observed in a skeletal context; therefore, proper analyses of skeletal indicators and dental radiographs may be impossible to assess.

Essentially, all of the DIs discussed in this study will fall under the umbrella term of PDI. However, for the sake of clarity, PDI is discussed in a separate section from PDI associated with restorative treatment (i.e., RDIDP). Please note, these criteria were used to organize the decedents' arrays for the survey questionnaire.

Dental Identifiers: Dental Pathological Conditions

According to Thomson and Johnson (2018), the ability to recognize deviations from normal radiographic anatomy is an important skill in dental radiography. For instance, researchers can differentiate between normal radiographic anatomy and pathology by the relative degree of radiolucency or radiopacity, size, and location on a tooth (Coleman and Nelson 1989; Iannucci and Howerton 2021; Thomson and Johnson 2018; Wood 2006). Please note, the relative degree of radiolucency refers to those structures that are softer and allow the passage of radiation (i.e., they appear black on an x-ray), and the relative degree of radiopacity refers to those structures that are radiodense and resist the passage of radiation (i.e., they appear white on an x-ray) (Iannucci and

Howerton 2021; Thomson and Johnson 2018). In this section, the following PDIs, as seen in Fig. 1, will be discussed: dental caries, periodontal disease, and periapical lesions. Distinguishing pathological features are discussed below.

Dental caries

Dental caries (i.e., tooth decay) is a multifactorial and multibacterial disease of the calcified tissues of teeth that results from the consumption of carbohydrates and the process of bacterial fermentation that occurs afterwards (Nelson 2015; Pilloud and Fancher 2019; Slootweg 2013; Zimmerman, Shumway, and Jenzer 2023). Dental caries is characterized by the breakdown of the tooth's outermost structure (i.e., enamel) due to bacteria, and when the breakdown of a tooth's structure reaches the underlying structures of the tooth (i.e., the dentin and pulp chamber), additional degradation of the tooth's structure occurs (Slootweg 2013; Zimmerman, Shumway, and Jenzer 2023). For dental caries to be considered a PDI in this study, they must leave a pathological signature on the skeletal elements of the oral cavity and be radiographically observable. Carious lesions are observed radiographically as recession of the tooth's outermost structure, (i.e., a radiolucency present in the enamel), and innermost structures (i.e., dentin, and pulp), because the region of decay is less dense than the surrounding anatomy (Iannucci and Howerton 2021; Thomson and Johnson 2018).

Periodontal disease

When dental caries is left untreated, bacteria cause the underlying structures of a tooth to decay. Essentially, bacteria invade the root surface of a tooth and cause the region to become inflamed (Slootweg 2013). For this reason, periodontal disease generally refers to an extensive range of inflammatory conditions that affect the supporting structure for the teeth within the mandible and maxilla (i.e., the periodontium)

(Nelson 2015; Pilloud and Fancher 2019). Periodontal disease is characterized by the degradation of bony tissues (Slootweg 2013). For periodontal disease to be considered a PDI in this study, the disease must leave a pathological signature on the skeletal elements of the oral cavity and be radiographically observable (i.e., the degradation of the bony tissues is evident). Periodontal disease is observed radiographically as recession of the alveolar bone (Iannucci and Howerton 2021).

Periapical lesions (i.e., pulpitis)

Periapical lesions and pulpitis are related, because inflammation of the pulpal tissue creates an infection in the region that manifests as degradation of the surrounding skeletal tissue (e.g., granuloma, cyst, or an abscess) (Nelson 2015; Pilloud and Fancher 2019). Specifically, this process occurs because the pulp cavity present in each tooth extends towards the root as a canal. The root canal opens into the periodontium through a small opening at the apex of a tooth called the apical foramen (Legge and Hardin 2015). The apical foramen provides a necessary network of communication between the tissue and pulp; therefore, when an infection does occur in the pulp of a tooth, the spread of inflammation into the surrounding area is significant. Notably, Pilloud and Fancher (2019) state that the term ‘periapical lesion’ is preferable to similar etiologies in a skeletal context, because it is impossible to positively identify or discern between the various manifestations of these pathological conditions as they are all designations of disorders of the soft tissue. Therefore, in a skeletal context, periapical lesions are observed as present/absent and by location (Pilloud and Fancher 2019). For periapical lesions to be considered a PDI in this study, the disease must leave a pathological signature on the skeletal elements of the oral cavity (i.e., a periapical lesion is determined to be present)

and be radiographically observable. Radiographically, when a periapical lesion is present in the pulp tissues and has manifested in the surrounding skeletal tissue, there is recession in the bony tissues (i.e., a radiolucency is present in the pulpal tissues and bony tissues) (Iannucci and Howerton 2021).

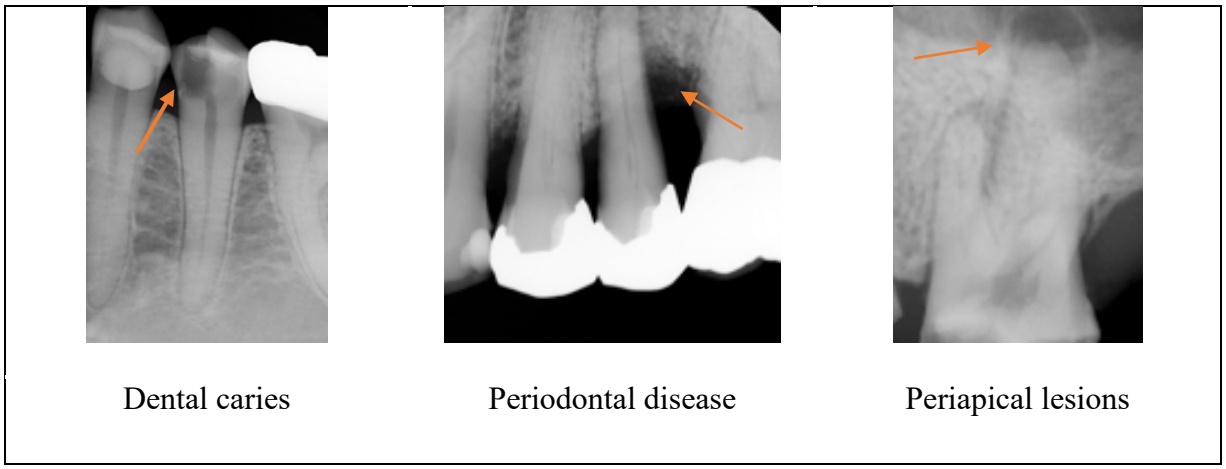


Fig. 1 Radiographic examples of pathological dental identifiers used in the survey questionnaire. The first radiograph on the far-left indicates dental caries present in a mandibular second-premolar. The second radiograph from the left indicates bone loss due to periodontal disease present in the maxillary posterior dentition. The radiograph on the far-right indicates a well-defined radiolucent periapical lesion at the apex of a maxillary molar. Radiographs obtained from the Washoe County Regional Medical Examiner's Office.

Dental Identifiers: Restorative dental identifiers associated with dental pathology

Generally, the presence of materials used in dental restorations is indicated in dental radiographs when common variances or alterations to normal oral maxillofacial anatomy are present (Thomson and Johnson 2018). Selected radiographs and photographs used in this study included a variety of RDIDP (e.g., fillings, crowns, implants, bridges, root canal therapy, and orthodontic appliances) as seen in Fig. 2. Researchers can differentiate between normal radiographic anatomy and restorative treatment by the relative degree of radiolucency or radiopacity, size and contour (i.e., the outline and form

of the tooth/prosthesis), and location on a tooth (Ahlqvist 2016; Iannucci and Howerton 2021; Picoli et al., 2019; Thomson and Johnson 2018; Wood 2006). Distinguishing restorative features are discussed below.

Fillings

According to Wood (2006), "Most cases of comparative identification use radiographic evidence of dental intervention (restorations, root fillings, crowns, extractions) as common points of identification" (S48). For instance, when restorative intervention occurs in a clinical context, fillings (e.g., resin/composite or amalgam) are a common restorative treatment of dental caries (Noort 2013). Carious lesions appear as radiolucent regions in the crown or root of a tooth when viewed on a radiograph (Iannucci and Howerton 2021). When carious lesions are removed by a dental provider and filled with either a resin/composite filling or an amalgam filling, the relative degree of radiolucency or radiopacity changes, and the region appears radiopaque (Iannucci and Howerton 2021; Thomson and Johnson 2018). In order for fillings to be considered a RDIDP in this study, restorative treatment must be skeletally indicated and radiographically observable (i.e., the region appears radiopaque on a dental radiograph, because a filling is present in the region).

Crowns

According to the AGD (2012), dental crowns are tooth-shaped "caps" that can be placed over a tooth to restore a tooth's shape, size, appearance, and overall strength. Dental crowns are cemented into place to cover the visible portion of a tooth. There are numerous types of permanent crowns used on the dentition: metal (e.g., gold, nickel, chromium, palladium), porcelain-fused-to-metal, all-resin, all-ceramic, and pressed ceramic (Cleveland Clinic 2020; Thomson and Johnson 2018). The materials used to

create crowns play a significant role in their radiographic appearance, due to variations in the degree of radiolucency or radiopacity of the material used. Radiographically, crowns appear as radiopaque tooth-shaped structures that cover the crown of a tooth or implant (Thomson and Johnson 2018). Crowns (including onlays and three-quarter crowns) were considered a RDIDP in this study if the restoration was present on the skeletal elements of the oral cavity (i.e., a crown is apparent on a tooth/implant), and the crown was radiographically observable (i.e., a radiopaque tooth-shaped structure covers the crown of a tooth/implant).

Bridges

Crowns are also used to hold a dental bridge in place (AGD 2012). Dental bridges are used when one or more teeth are missing, by replacing the missing teeth with artificial (false) teeth (ADA SCDI 2015). Typically, a bridge is made up of crowns on either side of the missing tooth/teeth (that are prepared for a crown), an artificial tooth is linked to the crowns, and the entire bridge is cemented in place to the prepared teeth (American College of Prosthodontists [ACP] n.d. -a). In order for bridges to be considered a RDIDP in this study, the restoration must be present on the skeletal elements of the oral cavity (i.e., a bridge is apparent on a tooth/implant to replace missing teeth), and the bridge is radiographically apparent. According to Thomson and Johnson (2018), when viewed radiographically, a bridge appears to be a series of fused radiopaque tooth-shaped structures that cover the crowns of multiple teeth (i.e., a multi-unit bridge) and missing teeth. Notably, a bridge's radiographic appearance on a radiograph (i.e., relative degree of radiolucency and radiopacity) will vary based on the materials used to create it (e.g.,

metal, ceramics, or a combination of both) (see ADA Division of Science 2015; Thomson and Johnson 2018).

Implants

Dental implants are a restorative treatment used to replace absent/missing tooth roots with small threaded posts (ACP n.d. -b). Dental implants are typically composed of tissue-friendly materials like titanium or ceramic. Implants are used to treat individuals who have lost one or more teeth due to caries, root fracture, bruxism, gum disease, maxillofacial injury, and congenitally missing teeth (ACP n.d. -b; Thomson and Johnson 2018). According to Ahlqvist (2016), there is an increasing number of individuals rehabilitated by implants, and this may prove beneficial in the human identification process. For example, in a skeletal context, oral implants are unique identifiers because of variation in their location, size, or crown and bridge attachment. Implants were considered a RDIDP in this study if an implant was skeletally indicated (i.e., an implant is present in the jaw) and radiographically observable (i.e., a radiopaque small threaded post is present in the jaw with a radiopaque crown, bridge, or abutment attached) (see Thomson and Johnson 2018).

Root Canal Therapy

Root canal therapy is a dental procedure that alleviates pain associated with an infected or abscessed tooth by cleaning and disinfecting the surfaces within a tooth, and filling the pulp chambers with a sealant (typically, gutta percha) (American Association of Endodontists 2017). Essentially, when dental caries or trauma of the tooth go untreated, bacteria can invade the internal structure of a tooth causing the tooth to become infected, and root canal therapy is necessary (ADA n.d. -b). For instance, Chavez de Paz (2007) notes that dental abscesses usually occur secondary to caries, periodontitis,

trauma, and infection. In addition, Ottaviani and colleagues (2014) states that the large majority of dental abscesses, "respond to surgical treatment, such as drainage of pus and disinfection of root canals" (499).

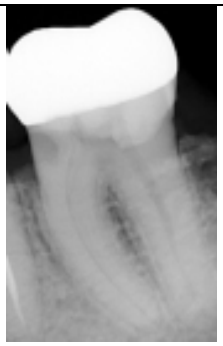
Thomson and Johnson (2018) note that when root canal therapy is conducted, gutta percha (an organic material) is used to fill the root canals of a tooth; therefore, the roots of the tooth appear radiopaque on a dental radiograph. In addition, the authors note that when the root canals are sealed with gutta percha, a restorative material is also placed at the crown of the tooth (which appears radiopaque) (e.g., filling, crown, bridge). Root canal therapy was considered a RDIDP in this study if restorative treatment was present on the skeletal elements of the oral cavity (i.e., root canal therapy is present in the roots of a tooth/teeth), and if that treatment could be observed on a dental radiograph (i.e., the roots of a tooth appear radiopaque and a radiopaque restorative material is likely placed at the tooth's crown).

Orthodontic Appliances

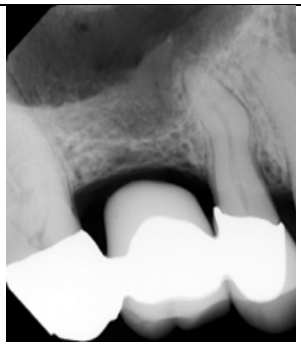
Orthodontics is a dental specialty focused on straightening the dentition and aligning the bite (ADA n.d. -a). Common orthodontic appliances include: braces, clear aligners, removable retainers, and palatal expanders (ADA n.d. -a). These materials are typically fabricated with metal (e.g., stainless steel or titanium), ceramics, or composite (Thomson and Johnson 2018). Orthodontic appliances have clear cosmetic benefits; however, ADA (n.d. -a) notes that there are a myriad of functional and health-related advantages to orthodontic treatment (i.e., restorative properties). For example, properly aligned teeth can improve chewing function, speech function, pain related to TMJ, and reduce risk for dental decay (e.g., caries, periodontitis).

Picoli and colleagues (2019) note that orthodontic appliances are distinctive tools for human identification, because of their unique type (e.g., braces, aligners, palatal expanders) and location in the oral cavity (e.g., tooth position, angulation in the arch, crown size/shape). Radiographically, orthodontic appliances (including surgical materials) can be readily identified by noting their distinctly shaped radiopacities (e.g., metal orthodontic bands, wires and brackets; and surgical wires, pins, and screws) (Thomson and Johnson 2018). Orthodontic appliances were considered a RDIDP in this study if an appliance or surgical material was present on the skeletal elements of the oral cavity, and if the appliance was radiographically observable (i.e., distinctly shaped radiopacities are present in the oral cavity).

Fillings



Crowns



Bridges

Root Canal Therapy

Implants

Orthodontic Appliances

Fig. 2 Radiographic examples of restorative dental identifiers associated with dental pathology used in the survey questionnaire. Radiographs obtained from the Washoe County Regional Medical Examiner's Office.

MATERIALS AND METHODS

Survey Questionnaire Design

A survey questionnaire was created in Qualtrics XM Software, Version [2023] of Qualtrics (Qualtrics, Provo, UT), a web-based survey interface. The survey was made available to participants throughout April 2023. The content of the survey was designed to explore which factors (i.e., the presence/absence of dental pathological conditions/restorations and respondents' expertise/experience) influence the ability to make a correct identification in dental radiographic comparisons. The survey and project were approved by the Institutional Review Board at the University of Nevada, Reno [2028404-1].

Participants and Setting

Forensic practitioners and students of various levels of expertise were invited to participate in the questionnaire survey. This approach was targeted and specific individuals were invited with known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology. An email was sent to each respondent asking for their participation. Once participation was confirmed, the survey questionnaire was distributed by an email containing a hyperlink to all questionnaire materials, including a consent form. All participation in the survey questionnaire was voluntary, and all data are anonymous and aggregated.

Survey Questionnaire Content and Procedure

The survey questionnaire was developed using dental arrays of sixty decedents from the Washoe County Regional Medical Examiner's Office (WCRMEO). Data were compiled between November 2022 and February 2023. The arrays include both AM and PM radiographs. These images were used in medicolegal death investigations and are representative of what would be available in forensic casework.

The AM dental radiographs obtained from the decedents' files included: 1) Bitewing Radiographs- a partial image of the upper and lower dentition, 2) Periapical Radiographs- an image of the entire tooth, 3) Full mouth survey radiographs- imaging of the entire dentition that includes a combination of bitewing and periapical radiographs, and 4) Panoramic radiographs- full images of the entire oral cavity (ABFO 2020). A Nikon D5600 Digital SLR Camera was used to take images of all AM radiographs that were typically found as paper copies in the decedents' case file in the WCRMEO.

The PM dental radiographs were obtained at the WCRMEO using DEXIS Imaging Suite Software, Version [2023] of DEXIS (DEXIS, Quakertown, PA). All PM dental radiographs included full mouth surveys of each decedent. The PM radiographs often included multiple images of each quadrant; therefore, the radiographs were re-organized to include the best image quality (i.e., clear image, appropriate orientation, and the best available view of the anatomy) (Forrest 2019). After the radiographs were chosen, screen captures were taken of the full mouth survey and isolated regions of the decedents' posterior dentition for inclusion in the survey.

The data were de-identified by confirming that all HIPAA identifiers were removed in accordance with UNR's Humans Subjects Protection Program (n.d.). The available data were reviewed to confirm the content was effective for addressing the

study aims and met cognitive pretesting procedures: the survey questions and response selections were clear and comprehensible, and the overall content was interpreted as planned (Collins 2003).

The final survey questionnaire was composed of three primary section blocks: 1) Consent to partake in the survey, 2) Qualitative data about the respondent, and 3) Comparative dental arrays. Overall, the survey questionnaire included 67 closed-ended questions. The first section asked the respondent to partake in the study and noted that the respondent's participation was voluntary. The second section requested the respondent to answer seven qualitative questions regarding their expertise in decedent identification using dental radiographs. Expertise was determined based upon the respondent's educational background (i.e., highest degree achieved), if the respondent was board certified, experience in handling forensic cases and dental radiographic comparisons, and total years practicing in MDIs (since receiving their highest degree). In the third section, the respondent was asked sixty questions in which they compared AM and PM radiographs to determine if the arrays belonged to the same individual (i.e., the arrays match) or if the arrays belonged to different individuals (i.e., the arrays did not match).

To address the hypothesis in this study, the sixty arrays were comprised of four types: 1) fifteen AM and PM radiographs of the same individual (i.e., they match) that display dental restorations and/or pathological conditions, 2) fifteen AM and PM radiographs of different individuals (i.e., they do not match) with dental restorations and/or pathological conditions, 3) fifteen AM and PM radiographs of the same individual (i.e., they match) without dental restorations and pathological conditions, and 4) fifteen AM and PM radiographs of different individuals (i.e., they do not match) without dental

restorations and pathological conditions. For the purposes of this study a pathological condition of the dentition was identified as: dental caries, periodontal disease, and periapical lesions.

The respondents were given one array per question, and were asked to mark 'Yes' if the arrays matched and 'No' if the arrays did not match. There were no opportunities to qualify responses (e.g., 'identification is probable', 'possible identification/match'), to ensure response selections remained clear and comprehensible (see Collins 2003). The arrays were provided to the respondent in random sequence and the same order was presented to each respondent. In addition, the arrays only included features of the posterior dentition (maxillary and mandibular premolars and molars), as the posterior dentition was often more clearly depicted on the radiographs than was the anterior dentition. The comparative images either displayed a single quadrant of the dentition (i.e., Upper Right Quadrant, Upper Left Quadrant, Lower Left Quadrant, and Lower Right Quadrant) or they displayed the crowns of the posterior maxillary and mandibular teeth.

The number of concordant dental identifiers (e.g., pathology, restorations, anatomy), and the presence of discrepancies (see ABFO 2020; ADA SCDI 2020; ASB Standard 148 2023) present in a dental radiograph has a demonstrated impact on the respondents' ability to interpret the dental radiographs for positive identification (Jayakumar and Mânica 2020). To account for this, respondents were asked to report which dental features were most important in the identification process for each determination: root morphology, cusp morphology, dental restorations, dental pathology, and other (i.e., fill in the blank). Definitions of these features were not provided for respondents, as authors wanted to rely on respondents' own definitions, rather than

providing them a rubric, to illuminate upon how respondents' expertise and experience influence their ability to make a correct identification in dental radiographic comparisons.

Fig. 3 Example of survey question using AM and PM radiographs of the same individual (i.e., they match) that display dental restorations and/or pathological conditions. Radiographs obtained from the Washoe County Regional Medical Examiner's Office.

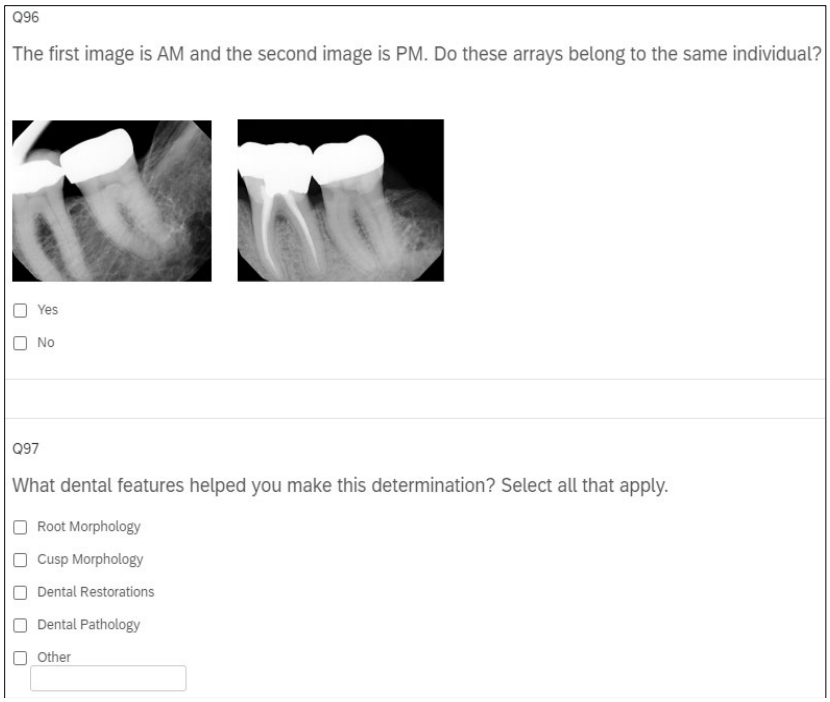


Fig. 4 Example of survey question using AM and PM radiographs of different individuals (i.e., they do not match) with dental restorations and/or pathological conditions. Radiographs obtained from the Washoe County Regional Medical Examiner's Office.

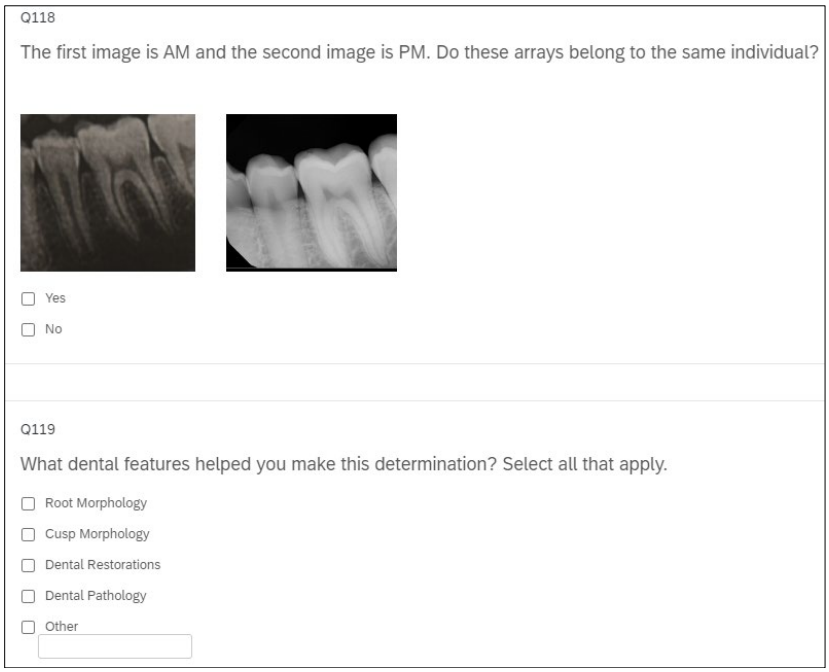


Fig. 5 Example of survey question using AM and PM radiographs of the same individual (i.e., they match) without dental restorations and pathological conditions. Radiographs obtained from the Washoe County Regional Medical Examiner's Office.

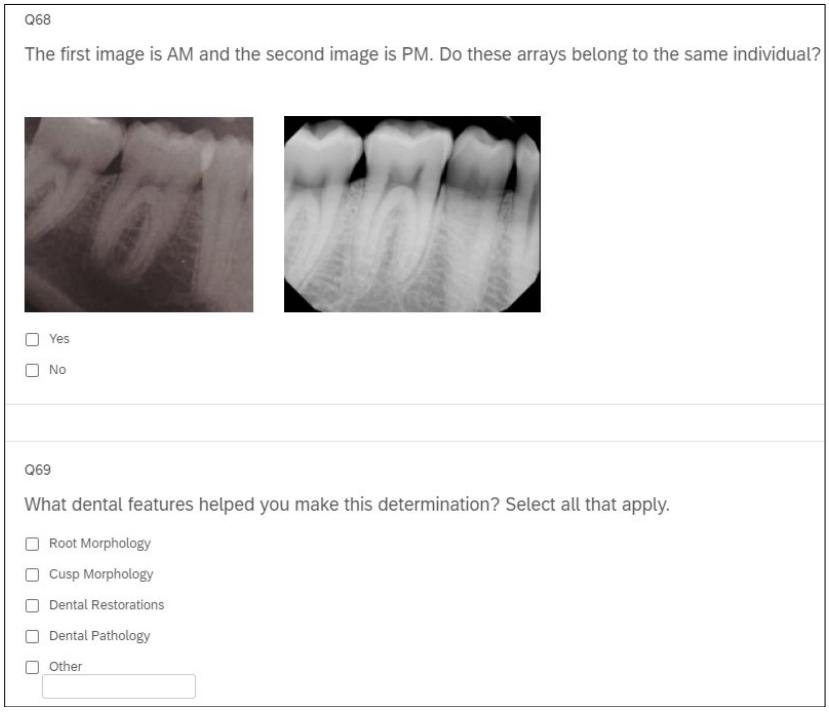


Fig. 6 Example of survey question using AM and PM radiographs of different individuals (i.e., they do not match) without dental restorations and pathological conditions. Radiographs obtained from the Washoe County Regional Medical Examiner's Office.

Statistical Analysis

For each observer the percentage of correct identifications for each array type was calculated. Descriptive statistics were used to describe the sample and results of the survey. Percentages and statistics were calculated in Microsoft Excel. To test the hypotheses in this study, 1) the percent of correct matches/non-matches was analyzed according to whether defined RDIDP and PDI were present or absent, 2) the percent of all DI used was analyzed based on the total of all correct matches/non-matches (i.e., original values), and 3) the percent of DI used for only correct matches was analyzed based on the total of correct matches, excluding non-matches, (i.e., correct values). For the purposes of this study, only completed surveys were used to tabulate results.

RESULTS

Qualitative Data of Respondents

The data output was generated using Qualtrics XM Software, Version [2023] of Qualtrics (Qualtrics, Provo, UT). An overall sample of six respondents were identified as meeting the inclusion criteria to participate in the questionnaire survey (i.e., individuals were invited with known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology). Six respondents completed the questionnaire survey in full. Table 1 summarizes the qualitative data of respondents.

Table 1. Qualitative data of respondents

	n	***%***
Highest degree achieved		
BA/BS	1	16.67%
MA/MS	3	50%
PhD	1	16.67%
MD	0	0.00%
DDS	1	16.67%
Certification		
Yes	2	33.33%
No	4	66.67%
Experience in dental radiographic comparisons		
Yes	2	33.33%
No	4	66.67%
Estimated total of dental radiographic comparisons completed by respondent		
N/A	3	50%
0	2	33.33%
1-99	0	0.00%
100-199	0	0.00%
200-299	0	0.00%
300-399	0	0.00%
400+	1	16.67%

Years experience with MDI		
0	4	66.67%
1-9	0	0.00%
10-19	1	16.67%
20-29	1	16.67%
30+	0	0.00%

Summary Responses of Respondents

Summary Responses: Scoring

The total possible score for correctly matching all 60 AM and PM dental radiographs in the questionnaire survey was 60 matches and the lowest possible matching score was 0 correct matches. Table 2 summarizes statistical observations made from all respondents' data per section (i.e., pathological conditions – match out of 15, pathological conditions – no match out of 15, no pathological conditions – match out of 15, and no pathological conditions – no match out of 15), and all respondents' overall score (i.e. all categories for all 60 arrays). Overall score values for all respondents are as follows: the mean correct matches ($\bar{x}$) was 50.17, the minimum correct matches (*min.*) was 45, the maximum correct matches (*max.*) was 56. The standard deviation (s) was 3.62 and the variance (s^2) was 13.14. The average time used to complete the questionnaire survey was 63 minutes. The average time used to complete the questionnaire survey for students (N=4) was 56 minutes and the average time for professionals (N=2) was 46 minutes. The matching radiographs with pathological conditions had the highest correct matches by respondents followed by non-matching radiographs with pathological conditions, matching radiographs without pathological conditions, and non-matching radiographs without pathological conditions.

Table 2. Summary of respondents (N=6) scores taken from questionnaire survey

Respondent	% correct pathological conditions - match (N=15)	% correct pathological conditions – no match (N=15)	% correct – no pathological conditions – match (N=15)	% correct – no pathological conditions – no match (N=15)	All Categories (N=60)
1	100%	73.3%	86. 7%	80%	85%
2	93.3%	86.7%	66. 7%	73.3%	80%
3	100%	66.7%	93.3%	60%	80%
4	93.3%	93.3%	93.3%	73.3%	88.33%
5	100%	93.3%	80%	100%	93.33%
6	60%	80%	66.67%	93.33%	75%
Average	91.1%	82.2%	81.1%	80%	83.6%
$\bar{x}$	13.67	12.33	12.17	12	50.17
min.	9	10	10	9	45
max.	15	14	14	15	56
s	15.59	10.89	12.23	14.61	3.62
s^2	2.43	1.19	1.50	2.13	13.14
se	6.36	4.44	5.00	5.96	1.62

Summary Responses: Overall values

Summary responses were calculated by the number of responses input into each section and expressed as a percentage of correct matches (Table 2). The percent matching radiographs with pathological conditions had the highest correct matches by respondents (91.1%), and its s^2 (2.43) did not overlap percentages of other sections. In contrast, all other sections had lower match accuracy rates ranging from 82.2% to 80% and their *s* are overlapping.

Match responses based on expertise and experience were calculated for professional respondents (N=2) and student respondents (N=4: Table 3) respectively. Statistical observations made from professional respondents and student respondents are summarized in Table 3. Professional Respondents' percent matching radiographs with pathological conditions had the highest correct matches by respondents. In contrast, all

other Professional Respondents' sections had lower match accuracy rates. Student Respondents had the highest match accuracy for percent matching radiographs with pathological conditions; whereas, all other sections had lower match accuracy rates.

Table 3. Summary responses of respondents (R): professional respondents (PR) and student respondents (SR)

R	correct pathological conditions - match		correct pathological conditions – no match		correct – no pathological conditions – match		correct – no pathological conditions – no match		All Categories	
PR	*%*	96.7%	*%*	76.7%	*%*	80%	*%*	66.7%	*%*	80%
	$\bar{x}$	14.5	$\bar{x}$	11.5	$\bar{x}$	12	$\bar{x}$	10	$\bar{x}$	48
	min.	14	*min.*	10	*min.*	10	*min.*	9	*min.*	48
	max.	15	*max.*	13	*max.*	14	*max.*	11	*max.*	48
	s	.71	*s*	2.12	*s*	2.83	*s*	1.41	*s*	2.27
	s^2	.5	s^2	4.5	s^2	8	s^2	2	s^2	5.14
SR	*%*	88.3%	*%*	85%	*%*	81.7%	*%*	86.7%	*%*	85.42%
	$\bar{x}$	13.3	$\bar{x}$	12.75	$\bar{x}$	12.25	$\bar{x}$	13	$\bar{x}$	51.25
	min.	9	*min.*	11	*min.*	10	*min.*	11	*min.*	45
	max.	15	*max.*	14	*max.*	14	*max.*	15	*max.*	56
	s	2.87	*s*	1.5	*s*	1.71	*s*	1.83	*s*	1.87
	s^2	8.25	s^2	2.25	s^2	2.92	s^2	3.33	s^2	3.5

A linear model was produced for predicting accuracy based on experience, presence of pathology, and if the radiographs were of the same individual. The model was produced in base R in the statistical computing platform R (R Core, 2021). The highest mean accuracy was for professionals identifying the same individual who had a pathological condition (96.7%; see Table 4). The only statistically significant ($p < 0.05$) factor that influenced accuracy was non-matching comparisons wherein accuracy was decreased by 20%. A decrease in accuracy of 17% was found when pathology was absent from radiographs, but was not significant ($p = 0.08$), and students were found to have

17% higher accuracy than professionals for non-matching radiographs, but this was also not significant ($p = 0.15$). However, in future studies a higher number of respondents could lead to more definitive results.

Table 4. Results of linear model

Variable	estimate	std error	t value	p value
Intercept	0.967	0.07	14.41	0.00
No pathology	-0.17	0.09	-1.76	0.08
No match	-0.20	0.09	-2.11	0.04
Student	-0.08	0.08	-1.01	0.31
Pathology – no match	0.07	0.13	0.50	0.62
Pathology - Student	0.10	0.12	0.86	0.39
No match: Student	0.17	0.12	1.43	0.15
Pathology: No match: Student	0.02	0.16	0.10	0.92

Summary Responses of Dental Identifiers used by Respondents

Respondents were asked to identify one or more of 5 total DI (i.e., root morphology, cusp morphology, dental pathology, dental restorations, and other DI [free response]) to determine which DIs were most informative in radiographic comparison. Notably, respondents were given the option to note alternative DI they used to match radiographs. Alternative DI were identified by respondents in the survey questionnaire and generally fell into the following categories: anatomy of the maxilla/mandible, pulp morphology, variability in tooth/teeth eruption, and radiographic anomalies. For the purposes of this study, alternative DI were not used to tabulate results. In addition, while dental radiographic comparisons including third molars were used in this study, some respondents may have treated them as PDI, while others did not, potentially skewing the data.

All Responses (Matching and Non-matching Dental Radiographs):Original Values and Correct Values

Original values indicate 1) the total of all correct matches/non-matches and 2) the percent of all DI used based on the total of all correct matches/non-matches. Correct values indicate 1) the total of correct matches, excluding non-matches, and 2) the percent of DI used for only correct matches based on the total of correct matches, excluding non-matches. Summary responses for original values and correct values were calculated by the total number of each DI used by individual respondents and are indicated in Table 5. Percentages of summary responses for original values and correct values used by all respondents were calculated for all sections and are indicated in Table 6. Correct values from all categories indicate that root morphology proved to be the most informative DI (i.e., the most used DI, based on percent value), followed by dental restorations and cusp morphology.

Table 5. Summary response of dental identifiers (DI) used by respondents (R). DI are represented by acronyms in the table: root morphology (RM), cusp morphology (CM), dental restorations (DR), dental pathology (DP), and other variables (O).

R	DI	Total correct pathological conditions -match		Total correct pathological conditions – no match		Total correct – no pathological conditions – match		Total correct – no pathological conditions – no match	
		Original	Correct	Original	Correct	Original	Correct	Original	Correct
1	RM	9	9	12	9	13	11	13	10
	CM	8	8	6	4	12	11	11	8
	DR	13	13	8	8	2	2	0	0
	DP	4	4	2	1	3	3	1	1
	O	1	1	4	3	4	2	0	0
2	RM	2	2	4	3	8	5	12	8
	CM	3	2	3	2	6	4	8	5
	DR	12	12	11	11	2	2	0	0
	DP	0	0	1	0	0	0	0	0
	O	1	1	2	2	2	2	2	2

3	RM	8	8	12	8	12	12	13	9
	CM	6	6	0	0	8	8	9	4
	DR	14	14	12	8	4	3	3	1
	DP	4	4	1	1	3	2	1	0
	O	7	7	5	4	3	3	0	0
4	RM	13	12	14	13	14	13	13	9
	CM	6	5	4	3	9	9	11	8
	DR	12	12	4	4	2	2	0	0
	DP	0	0	1	1	3	3	2	1
	O	0	0	0	0	0	0	0	0
5	RM	4	4	12	11	9	7	13	13
	CM	2	2	4	3	9	7	11	11
	DR	13	13	13	13	2	2	0	0
	DP	3	3	2	2	3	2	2	2
	O	1	1	0	0	0	0	0	0
6	RM	6	6	7	5	8	7	7	6
	CM	5	4	2	2	9	8	4	4
	DR	9	8	7	5	2	2	0	0
	DP	2	1	1	1	2	2	0	0
	O	0	0	3	3	4	0	6	6

Table 6. Summary response of dental identifiers (RM, CM, DP, DR, O) of respondents (R)

DI	% Total correct pathological conditions -match		% Total correct pathological conditions – no match		% Total correct – no pathological conditions – match		% Total correct – no pathological conditions – no match		% All Categories	
	Original	Correct	Original	Correct	Original	Correct	Original	Correct	Original	Correct
RM	46.7%	45.6%	67.8%	54.44%	71.11%	61.11%	78.9%	61.11%	66.1%	55.6%
CM	33.33%	30%	21.11%	15.6%	58.9%	52.22%	60%	44.44%	43.3%	35.6%
DR	81.11%	80%	61.11%	54.44%	15.6%	14.44%	3.33%	1.11%	40.3%	37.5%
DP	14.44%	13.33%	8.9%	6.7%	15.6%	13.33%	6.7%	4.44%	10.11%	9.7%
O	11.11%	11.11%	15.6%	12%	13%	7.8%	8.9%	8.9%	12.5%	10.3%

To determine which DI were most informative in radiograph comparisons based on respondents' expertise and experience, responses (i.e., original values and correct values) were calculated individually for professional respondents (N=2), and for all

student respondents (N=4). The data were separated into two groups of respondents (i.e., professional respondents and student respondents) and expressed as a percentage (Table 7). Root morphology proved to be the most informative for both categories of respondents, followed by dental restorations for professionals and cusp morphology for students.

Table 7. Summary response of dental identifiers (RM, CM, DP, DR, O) of respondents (R) (professional (PR) and student (SR))

R	RM		CM		DR		DP		Other	
	Original	Correct	Original	Correct	Original	Correct	Original	Correct	Original	Correct
PR	59.2%	45.8%	35.8%	25.8%	48.3%	42.5%	8.3%	5.8%	18.3%	17.5%
SR	69.6%	60.42%	47.08%	40.42%	36.25%	35%	12.92%	11.25%	9.58%	6.67%

DISCUSSION

Array Categories

Regarding respondents' match accuracy per array category, respondents had the greatest percent match accuracy for radiographs taken from the same individual (i.e., they match) that display RDIDP and/or PDI, and its s^2 (2.43) did not overlap percentages of other sections. In contrast, respondents match accuracy was lower in all other sections by an average of 9.93% and their *s* are overlapping. This result suggests radiographs taken from the same individual (i.e., they match) that display RDIDP and/or PDI were more likely to have a high match accuracy than other sections. Despite other sections' values not being significantly different from one another, respondents still performed well (82.2% to 80% accuracy). Match accuracy results for these sections verify that the most correct matches occurred when pathology was present for correct matches and non-

correct matches. Moreover, in both sections with pathology and with no pathology, the non-match arrays had a lower match accuracy than arrays of the same individual. These results suggest a propensity towards false positives (indicating a match when there is not a match). While the sample size here is low, this could be a promising avenue for future research.

Respondent Experience

Despite variation in respondents' expertise and experience, respondents had an average match accuracy rate of 83.6% and a match accuracy range of 93.33% to 75%. No respondents achieved a perfect score in the survey, in terms of correctly matching all 60 dental radiographs. Professional respondents had an overall match accuracy of 80% and student respondents had an overall match accuracy of 85.42%. Of note is that student respondents outperformed professional respondents by 5.42%. There were no differences found between student respondents' array sections in terms of mean accuracy. In contrast, professional respondents' percent matching radiographs with pathological conditions had the greatest mean accuracy compared to other sections. There were no differences between professional respondents and student respondents in terms of matching dental radiographs in all other sections (see Table 3).

Student Respondents

Previous studies have evaluated how student respondents' expertise and experience affects their ability to make correct matches in CDA using a multitude of DI (Bradshaw et al., 2022; Pinchi et al., 2012; Wenzel, Richards, and Heidmann 2010). For instance, Wenzel, Richards, and Heidmann (2010) evaluated the ability of undergraduate dental students (N=10) to match AM and PM radiographs of healthy jaws from 51 dry human skulls, with experts (N=3) acting as controls. Notably, none of the teeth had

restorations; however, 25% of the skulls were from subadults with minimal tooth wear, and 75% were from older individuals with more severe tooth wear. The authors reported that the pregraduate students performed poorly in comparison to the experts (2 forensic odontologists and 1 radiologist). Wenzel, Richards, and Heidmann (2010: pg 8) add, "When visually matching dental radiographs of teeth with no restorations or other dental work, a correct match depends on the observer's ability for pattern recognition, that is, to analyze and compare the anatomical pattern of crowns, roots, pulp chambers, interproximal marginal bone, etc". The authors demonstrated that correctly matching radiographs can be achieved without PDI and RDIDP, based on the observer's ability for pattern recognition; however, they did not report on how a lack of these DI may have influenced match accuracy rates. In addition, the study demonstrated that controls' expertise may have proven invaluable to the simulated forensic case; unfortunately, the study did not report on how differences between controls' training affected their performance. Furthermore, a lack of diversity between controls' training may have influenced comparisons made between match accuracy rates reported by professionals and students. Therefore, within the context of this study, the researchers sought to explore how student respondents' expertise and experience affected their ability to make correct matches in CDA using PDI and RDIDP.

In this study, student respondents collectively performed well with match accuracy rates ranging from 88.33% to 81.67% in all individual sections, and an overall match accuracy rate of 85.42%. Student respondents' match accuracy rates are similar to match accuracy rates reported by Bradshaw and colleagues' (2022) study inclusive of 31 senior dental hygiene students who matched AM and PM radiographs, with PDI and

RDIDP present, with a match accuracy rate of 93.5% to 83.9%. Bradshaw and colleagues' data suggests that the senior dental hygiene students' formal education and baseline skill set provided students with transferable match accuracy skills. In addition, the data suggests that the senior dental hygiene students' utilized PDI and RDIDP to successfully achieve high match accuracy rates; thus, demonstrating the utility of these DI in CDA.

In a similar fashion, Pinchi and colleagues (2012) conducted a study in which they evaluated the potential influence of experts' qualifications, training, and cognitive bias on the accuracy of matching AM and PM dental radiographs for identification. Radiographs were divided into three levels of complexity: 1) Low difficulty- six to nine teeth (or teeth area) that include many radiographic features (i.e., anatomical traits, PDI, RDIDP), 2) Medium difficulty- at least three teeth that include a moderate number of radiographic features, and 3) High difficulty- one of two teeth without specific radiographic features. The study consisted of 78 differently experienced and qualified experts: specialists in emergency care, specialists in legal medicine, pregraduate dental students, dentists, dentists educated in forensic odontology, and forensic odontologists. Regarding match accuracy reports reported for student respondents by Pinchi and colleagues, pregraduate dental students' were found to have a match accuracy rate of 89% to 82%, similar to match accuracy rates reported in this study.

High match accuracy rates reported by Pinchi and colleagues (2012: Table 1) suggest that pregraduate dental students' successfully utilized radiographic features (i.e., anatomical traits, PDI, RDIDP) for correct attributions (true positives and true negatives) for low difficulty matches (95%) and medium difficulty matches (88%) in comparison to

high difficulty matches (72%). Results suggest that pregraduate dental students' students had higher match accuracy rates for dental radiographic comparisons that presented with a moderate to high amount of DI. However, the most experienced and qualified experts (i.e., forensic odontologists) consistently outperformed operators with less experience and qualifications; although, dentists educated in forensic odontology did not necessarily outperform dentists without education in forensic odontology, possibly alluding to cognitive bias, "mainly the so-called observer effect" (pg: 252). Despite differences in participants' experience and qualifications, the study alludes to the fact that dental students with formal education and a baseline skill set perform well in matching dental radiographs for identification. However, this study also alludes to the fact that professional specialists consistently outperformed other operators, including student respondents (i.e., respondents with less experience and qualifications), indicating specialists with more expertise and experience may be more qualified to match AM and PM dental radiographs for identification purposes.

In the present study, despite student respondents being at differing levels in their expertise and experience, results for student respondents suggest that students' expertise and experience in dental anthropology, the forensic sciences, and forensic odontology may prepare them with transferable knowledge to accurately match dental radiographs. Moreover, similar studies demonstrate comparable match accuracy rates when CDAs are conducted. While student respondent results suggest that students' expertise and experience plays a potentially useful role in make correct matches in CDA, Page and colleagues (2018: pg 188) suggest "that only people with dental qualifications and experience should be considered to undertake the task of matching AM and PM

radiographs". As there are other aspects to radiographic comparisons beyond accurate matches, such as accurately taking PM radiographs, result interpretation, and expert witness testimony. All of which require advanced training and demonstrated expertise.

Professional Respondents

Noting Page and colleagues' (2018) statement on expertise, previous studies have evaluated how professional respondents' expertise and experience affects their ability to make correct matches in CDA (Balla and Forgie 2017; Gorza and Mânica 2018; Khan, Franco, and Mânica 2023; Page et al., 2018; Pinchi et al., 2012; Sholl and Moody 2001). For instance, Sholl and Moody (2001) evaluated the influence of operators training and influence to assess the value of dental radiographs for personal identification. Notably, this study did not utilize dental radiographs with PDI or RDIDP present. The author determined that the 'viewers' (i.e., three groups of forensic odontologists, dental vocational trainees, and dental trainee hygienists) knowledge did not correlate well with the number of correct matches. In addition, while information regarding the utility of DI were lacking in the study, respondents were cited as utilizing root morphology and alignment most frequently to make a correct match. However, this conclusion was not supported by any numerical data.

Balla and Forgie (2017) evaluated 22 examiners (i.e., senior clinicians, recently qualified dentists, post graduate dental students and forensic specialists) comparing 7 sets of radiographs to determine the impact of observer qualifications and their clinical experience on CDA using restoration and caries free bitewing radiographs taken four years apart. The finding demonstrated that examiners correctly identified 78.5% to 71.5% of matches, and examiners cited crown morphology, pulp morphology, and root outline

as being the most useful DI in matching radiographs. Regarding observer qualification and clinical experience, the finding suggest that clinical experience is not related to making correct matches; rather, formal training in dental identification may be helpful so that examiners with varied experience levels can contribute to forensic identification efforts. Regarding the utility of non-pathological DI, "examiners who did pairing based on multiple anatomical features rather than one identified more correct pairings" (pg: 4), demonstrating the utility of non-pathological DI. Similar to Sholl and Moody (2001), Balla and Forgies' research did not utilize dental radiographs with PDI or RDIDP present; therefore, information regarding the utility of PDI were lacking in the study. In addition, numerical data regarding which DI were most/least used was lacking as examiners self-reported and radiographs used were limited to bitewings.

Khan, Franco, and Mânica (2023) investigated experts' opinions on the interpretation of dental identifiers from intraoral radiographs utilizing a web-based survey distributed to FOs' internationally. In addition, the survey explored which DI's were informative for making correct matches: morphological (e.g., crown morphology, root morphology, pulp morphology), therapeutic (e.g., crown, restorations, endodontic treatment), and pathologic features (e.g., caries, pulpal infection, bone loss). The survey consisted of three simulated scenarios of human identification. Scenarios #1 and 2 included radiographic comparisons with therapeutic identifiers and scenario #3 did not include evidence of dental treatment. The survey was completed by 57 FOs and results indicate, "The simulated case that involved therapeutic features (dental restorations) was positively identified by 56 participants (98%), while the case without therapeutic identifiers was identified only by 14 participants (24%)" (pg: 1). In general, cases with

unrestored teeth had higher rates of false negatives and the combinations of morphological and therapeutic features were determined to be the best approach for matching radiographs. The FO's relied on restorations more often, followed by tooth morphology and bone features. While FO's showed proper knowledge of dental features and their importance in human identification, cases with unrestored teeth had higher false negative rates suggesting expert performance in CDA is influenced by radiographic anatomy and its subjective interpretation. Similarly, in the present study, the authors found that the presence of dental identifiers has a notable effect on match accuracy rates, demonstrating that cases that match (i.e., radiographs from the same individual) with therapeutic dental identifiers (i.e., RDIDP) had higher rates of positive identification than cases without therapeutic identifiers. While Khan, Franco, and Mânica (2023) provide excellent corroborative evidence for the present study; unfortunately, their study lacked respondent diversity pertaining to expertise and experience. Therefore, within the context of the present study, research sought to expand upon past studies by 1) exploring how a variety of forensic practitioners' expertise and experience affects their ability to make correct matches in CDA, 2) how respondents' use of PDI and RDIDP affected their ability to make correct matches in CDA using a variety of dental radiographs (i.e., bitewings, periapicals, full mouth surveys, and panoramic radiographs), and 3) interpreting those results using conventional statistics.

In this study, professional respondents collectively performed well with an average accuracy rate of 80% for all sections, although neither professional respondent achieved a perfect score. However, the average accuracy for individual sections ranged from 96.67% to 66.67%. Professional respondents' overall match accuracy rates match

accuracy rates reported by Page and colleagues (2018) who aimed to evaluate the accuracy of AM and PM dental radiographic matching by 29 dentists and forensic odontologists. Match accuracy rates demonstrated that the likelihood of a true match was 89.3% and a declared nonmatch was likely to be a true non-match 85.6% of the time. In addition, similar to this study, no practitioner achieved a perfect score.

In sum, match accuracy values indicated from student respondents and professional respondents, based on expertise and experience, demonstrate that both groups performed well when matching dental radiographs to successfully complete the questionnaire survey. This result suggests that people with known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology may be able to make correct matches in CDA. However, the inclusion criteria for respondents to participate in this study did exclude individuals without known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology. Therefore, it is unknown if individuals lacking these experiences would have had a lower match accuracy. In addition, the data suggest that professional respondents outperformed student respondents in matching radiographs with pathological conditions, but all respondents performed similarly in all other sections. Differences in professional respondents and student respondents performances in matching radiographs with pathological conditions may be indicative of differences in their expertise and experience, or attributable to cognitive bias.

Regarding opportunities for cognitive bias among professional and student respondents, Page and colleagues (2018) note that there is some inconsistency of process among practitioners when using a dichotomous choice in declaring a match/non-match.

Essentially, discrepancies in interpretation of match accuracy between IOFOS, ABFO, and other scales demonstrate that differences in individual practitioners proficiencies (i.e., expertise and experience) may bias how they interpret the presence/absence of DI and the degree of expression to which DI present in CDA. In conjunction with Page and colleagues study, Pinchi and colleagues' (2012) exploration of how cognitive bias influences participants of different levels of experience and qualifications match accuracy demonstrated that the most experienced and qualified experts consistently outperformed operators with less experience and qualifications. However, differences in education (dentists with education in forensic odontology) demonstrated that some practitioners did not necessarily outperform others with less education (i.e., dentists without specialized education in forensic odontology), possibly alluding to cognitive bias.

In the present study the s^2 of all comparisons are very similar, except for professionals identifying correct matches with pathological conditions. This had very low s^2 compared to all other sets. Also, students had consistent correct rates across all categories, whereas professions had lower rates for non-match categories. In conjunction with corroborative literature, the data supports the authors' proposition that cognitive bias influenced the present study's match accuracy rates achieved by respondents, because none of these observations could have been made without separating matching and pathology into separate groups. However, more data are needed to fully verify this result.

Respondent Matching and Use of Dental Identifiers

Similarities and inconsistencies between AM and PM data are beneficial for CDA, because the presence/absence of DI (i.e., RDIDP and PDI) support the inclusion or exclusion of dental evidence for human identification (Gorza and Mânica 2018). The

PDIs selected for use in the questionnaire survey included: dental caries, periodontal disease, and periapical lesions. RDIDP selected for used in the questionnaire survey included: fillings, crowns, implants, bridges, root canal therapy, and orthodontic appliances. In this study, half of all dental radiographs contained RDIDP and PDI (15 matches and 15 non-matches) and the remaining 30 dental radiographs did not contain RDIDP and PDI (15 matches and 15 non-matches). The aim being to determine if the presence/absence of DI improves match accuracy in CDA and to determine which DIs were most/least valuable for correctly identifying dental radiographic matches and non-matches.

Respondents identified one or more of 5 total DIs to determine which were informative in matching radiographs. For all responses (matching and non-matching dental radiographs), original values for DIs were overall less informative in matching radiographs than correct values. Correct values indicate that respondents used root morphology most frequently followed by dental restorations, cusp morphology, other DIs (free response), and dental pathology. For all *matching* dental radiographs, correct values indicate that respondents used root morphology most, followed by dental restorations, then cusp morphology , dental pathology, and other DI (free response). For all *non-matching* dental radiographs, correct values indicate that respondents used root morphology most often, followed by cusp morphology, dental restorations, other DI (free response), and dental pathology least often. It should be noted here, that only half of the radiographs had dental pathological conditions; therefore, the presence of dental pathology is key in the percentage of its use as a DI in the radiographs.

Sholl and Moody (2001) evaluated ‘viewers’ (i.e., three groups of forensic odontologists, dental vocational trainees, and dental trainee hygienists) use of dental identifiers in matching AM and PM dental radiographs. The authors reported that root morphology and alignment were cited most frequently for facilitating matches between AM and PM dental radiographs; however, this conclusion lacked numerical data. In a more recent study by Angelakopoulos and colleagues (2017), the researchers investigated the uniqueness of clinical dental identifiers in intra-oral photographs and panoramic and lateral cephalometric radiographs from 1,727 subjects. The researchers determined that clinically detectable dental identifiers (CDDI) related to morphology (e.g., the shape of the incisors, the shape of the frontal sinus) were the most unique dental identifiers, demonstrating their utility in CDA, compared to treatment properties (e.g., fillings, bridges and their components, orthodontic brackets).

In a similar study by Du and colleagues (2020), researchers evaluated 920 panoramic radiographs from 460 live patients to determine which oral and maxillofacial identifiers (i.e., dental morphology, tooth number/position, dental treatment and pathology, morphological identifiers of the jaw, and pathological identifiers of the jaw) were most valuable for identification purposes. Similar to Angelakopoulos et al., (2017), Du and colleagues determined that DI relating to dental morphology were most informative for dental identification; however, researchers notably determined that DI associated with pathology (i.e., RDIDP and PDI) were also informative for dental identification. Unfortunately, match accuracy based on DI associated with pathology was not determined in this study, although similar studies provide corroborative evidence supporting the utility of therapeutic DI (i.e., RDIDP) (see Picoli et al., 2019; Wood

2006). Regarding DI associated with pathology, Du et al., (2020: pg 914) states, “their stability is relatively poor and might change with the progression of disease. This finding should be considered when applying these identifiers, which are preferably applied in conjunction with others.”.

In consideration of Du and colleagues’ statement and corroborative studies (see Bradshaw et al., 2022; Gorza and Mânica 2018; Wood 2006), the present study affirmed that using PDI in conjunction with RDIDP provided a more comprehensive view of how dental pathological conditions manifest in the oral cavity (i.e., presence of a pathological condition and the potential subsequent dental treatment provided). Researchers determined that respondents had the greatest match accuracy for sections in which most dental pathology were present for correct and non-correct matches.

Similar studies found that match accuracy rates declined for studies in which little to no CDDIs were present among a variety of participants (e.g., dental students, dentists, and forensic experts). For instance, Bradshaw and colleagues (2022) reported that participants matching AM and PM had lower match accuracy rates for difficult cases with 1-10 CDDI ranging from 58.1% to 41.9%; although, this study lacked a variety of participants. Pinchi and colleagues (2012) reported reduced match accuracy for all participants in cases lacking DI. Similarly, Gorza and Mânica (2018) reported that 19 forensic experts participating in a web-based questionnaire comparing AM and PM dental records had increased match accuracy rates in cases with more DI present. In addition, the study found that forensic experts self-reported that their match accuracy rates were negatively affected when there was insufficient data to make a match (i.e., a lack of DI negatively affected experts match accuracy rates).

CONCLUSION

The results of this study suggest that the presence of dental identifiers has a notable effect on match accuracy rates, particularly when radiographs are of the same individual. Although, the non-match category with pathological conditions had a higher accuracy rate than the arrays without pathological conditions, even though the difference was small (see Table 2). The survey questionnaire's binary decision process likely influenced match and non-match accuracy rates in conjunction with which DI were most/least used by respondents to achieve correct matches in CDA. Future research of this nature would benefit from additional radiographs per individual and options beyond match/non-match (e.g., identity established, identity probable, identity possible, identity excluded) as well as information regarding time lapse between AM and PM radiographs.

Despite variation in respondents' expertise and experience, no respondents achieved a perfect score in the questionnaire survey, and there no differences among respondents groups. These results indicate that people with known experience and expertise in dental anthropology, the forensic sciences, and forensic odontology may be able to make correct matches in CDA. However, while CDAs are invaluable to MDI, comparative literature suggests that only people with dental qualifications and experience should conduct CDAs in MDI. Moreover, the goal of forensic practitioners conducting CDAs is not necessarily to validate; rather, to interpret the evidence available and imbue their expertise in forensic reports as necessary for expert witness testimony.

The goal of this study is to help inform future research concerning validation in CDAs. This study suggests that PDIs are important in identifying correct dental

radiographic matches. Knowledge of dental anthropology and anatomy are transferable skills in reviewing dental radiographs, but do not replace expertise in forensic odontology. Preliminarily, this study indicates there may be a tendency towards false positives, supporting the authors' proposition that cognitive bias influenced the present study's match accuracy rates achieved by respondents, because none of these observations could have been made without separating matching and pathology into separate groups. More data are needed to fully verify results and future studies would benefit from a larger data set with more contextual information available to survey respondents.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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APPENDIX

A1 Recruitment Page

RE: Volunteers Needed for a Research Project Evaluating the Influence of Pathological Conditions on Dental Radiographic Comparisons

Hello,

You are being asked to participate in a research study (IRB# 20-011745) about the influence of pathological conditions on dental radiographic comparisons and the ability to make a correct match between antemortem and postmortem radiographs. Your participation will help us better understand how individuals from various backgrounds evaluate dental radiographs for positive/scientific identifications.

You have been asked to take part in this research because you are considered to have knowledge of dental anatomy/radiographs or have significant experience working within the medicolegal field.

If you agree to participate you will complete a survey of 60 radiographic arrays of antemortem and postmortem radiographs collected from the Washoe County Regional Medical Examiner's Office. All radiographs are de-identified. You will be asked to identify if the two radiographs are from the same person and to identify what factors were most important in making your assessment. The survey should take around 30-60 minutes to complete.

There are no anticipated risks from participating in this research. All participation is voluntary, and all data are anonymous and aggregated. Names of participants will not be maintained. The primary inconvenience or discomfort you may reasonably anticipate is the time required to participate in the interview or score interview transcripts.

Please understand your participation is voluntary, and you have the right to withdraw your consent or discontinue participation at any time without penalty.

If you decide to participate, please respond to this email. One of the PIs will send you a link to the Qualtrics survey for completion.

<u>NOTE:</u> No minors (individuals aged under 18 years) or any other at-risk populations are eligible to participate in this survey.

Thank you for your time and consideration.

Marin Pilloud

Jenevieve Walbrecker

Department of Anthropology

University of Nevada, Reno

Questions may be directed to the principal investigator at any time:

Marin A Pilloud, PhD, D-ABFA
Associate Professor
Department of Anthropology
775-682-7693
mpilloud@unr.edu

A2 Consent Form

University of Nevada, Reno
Consent Form Template, Social Behavioral or Educational Research

Title of Study:	**Radiographic Comparison Survey for Positive Identification**
Principal Investigator:	**Marin Pilloud**
Co-Investigators / Study Contact:	**Jenevieve Walbrecker**
Study ID Number:	**IRB# 20-011745**

SUMMARY OF KEY ELEMENTS:

The purpose of this research is to evaluate the role of pathological conditions in dental radiographic comparisons leading to positive identification.

You have been asked to take part in this research because you are considered to have knowledge of dental anatomy/radiographs or have significant experience working within the medicolegal field.

If you agree to participate you will complete a survey of 60 radiographic arrays of antemortem and postmortem radiographs collected from the Washoe County Regional Medical Examiner's Office. All radiographs are de-identified. You will be asked to identify if the two radiographs are from the same person and to identify what factors were most important in making your assessment. The survey should take around 30-60 minutes to complete.

Introduction

You are being invited to participate in a research study. Before you agree to be in the study, read this form carefully. It explains why we are doing the study; and the procedures, risks, discomforts, benefits and precautions involved.

At any time, you may ask one of the researchers to explain anything about the study that you do not understand.

You do not have to be in this study. Your participation is voluntary.

Take as much time as you need to decide. If you agree now but change your mind, you may quit the study at any time. Just let one of the researchers know you do not want to continue.

Why are we doing this study?

We are doing this study to identify which factors influence the ability to make a correct identification between antemortem and postmortem radiographs. With the expectation that the presence of dental pathological conditions will lead to more correct identifications.

Benefits of research cannot be guaranteed but we hope to learn how positive identifications are made in forensic odontology.

Why are we asking you to be in this study?

We are asking you to be in this study because you are considered to have knowledge of dental anatomy/radiographs or have significant experience working within the medicolegal field.

How many people will be in this study?

We expect to enroll between 10 and 15 participants who will participate in the survey virtually.

What will you be asked to do if you agree to be in the study?

If you agree to participate in the survey you will view 60 radiographic arrays of antemortem and postmortem radiographs collected from the Washoe County Regional Medical Examiner's Office. All radiographs are de-identified. You will be asked to identify if the two radiographs are from the same person and to identify what factors were most important in making your assessment.

How long will you be in the study?

The study will take between 30 and 60 minutes of your time.

What are your choices if you do not volunteer to be in this research study?

You should only participate if you want to do so. You will not lose any services, benefits or rights you would normally have if you choose not to take part.

What if you agree to be in the study now, but change your mind later?

You do not have to stay in the study. You may withdraw from the study at any time by informing the PIs.

What if the study changes while you are in it?

If anything about the study changes or if we want to use your information in a different way, we will tell you and ask if you if you want to stay in the study. We will also tell you about any important new information that may affect your willingness to stay in the study.

Is there any way being in this study could be bad for you?

There are no anticipated risks from participating in this research. All participation is voluntary, and all data are anonymous and aggregated. Names of participants will not be maintained. The primary inconvenience or discomfort you may reasonably anticipate is the time required to complete the survey.

What happens if you become injured because of your participation in the study?

There should be no injury due to participation in the online survey.

Will being in this study help you in any way?

We cannot promise you will benefit from being in this study.

Who will pay for the costs of your participation in this research study?

No costs are associated with participation in this study.

Will you be paid for being in this study?

You will not receive any payment for being this study.

Who will know that you are in in this study and who will have access to the information we collect about you?

The researchers, the University of Nevada, Reno Institutional Review Board will have access to your study records.

How will we protect your private information and the information we collect about you?

We will treat your identity with professional standards of confidentiality and protect your private information to the extent allowed by law. We will do this by anonymizing data and keeping all records secure.

We will not use your name or other information that could identify you in any reports or publications that result from this study unless you provide express written permission to do so.

Your identifiers might be removed and the de-identified information used for future research or distributed to another investigator without additional informed consent from you.

Do the researchers have monetary interests tied to this study?

The researchers and/or their families have no monetary interests in this project.

Whom can you contact if you have questions about the study or want to report an injury?

At any time, if you have questions about this study, contact Marin Pilloud 775-682-7693.

Whom can you contact if you want to discuss a problem or complaint about the research or ask about your rights as a research participant?

You may discuss a problem or complaint or ask about your rights as a research participant by calling the University of Nevada, Reno Research Integrity Office at (775) 327-2368. You may also use the online *Contact the Research Integrity Office* form available from the *Contact Us* page of the University's Research Integrity Office website.

Agreement to be in study

If you agree to participate in this study, you must sign this consent form. We will give you a copy of the form to keep.

Participant's Name Printed	
Signature of Participant	Date
Signature of Person Obtaining Consent	Date