The radiographic diversity of dental patterns for human identification

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The radiographic diversity of dental patterns for human identification — systematic review and meta-analysis

Abstract

This study aimed to revisit the scientific literature related to the diversity of dental patterns observed in radiographs. The rationale was to find evidence to support dental human identifications. A systematic review was performed following the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P). Strategic search was accomplished in five electronic data sources (SciELO, Medline/Pubmed, Scopus, Open Grey and OATD) were searched. The study model of choice was observational analytical cross-sectional. The search resulted 4.337 entries. The sequential screening based on title, abstract and full-text reading led to 9 eligible studies (n = 5.700 panoramic radiographs) published between 2004 and 2021. Studies from Asian countries were predominant (e.g., South Korea, China, and India). All the studies showed low risk of bias (measured according to the Johanna Briggs Institute's critical appraisal tool for observational cross-sectional studies). Morphological, therapeutic, and pathological identifiers were charted from radiographs to create dental patterns across studies. Six studies (n = 2.553 individuals) had similar methodology and outcome metrics and were included in the quantitative analysis. A meta-analysis was performed and revealed a pooled diversity of the human dental pattern of 0.979 combining maxillary and mandibular teeth. The additional subgroup analysis with maxillary and mandibular teeth have a diversity rate of 0.897 and 0.924, respectively. The existing literature shows that human dental patterns are highly distinctive, especially if morphological, therapeutic and pathological dental features are combined. The diversity of dental identifiers found in the maxillary, mandibular and combined arches is hereby corroborated by this meta-analyzed systematic review. These outcomes support applications for evidence-based human identification.

Keywords: Dental patterns; Forensic dentistry; Human identification; Radiograph.

The radiographic diversity of dental patterns for human identification – systematic review and meta-analysis

Introduction

According to the International Committee of the Red Cross (ICRC), human identification can be established by matching *antemortem* (AM) and *postmortem* (PM) dental features and fingerprints, DNA with reference samples, and other unique identifiers, such as numbered surgical implants and prostheses.[1] The contribution of dental features to human identification is corroborated by the International Criminal Police Organization (INTERPOL) and is listed among the primary means for human identification together with friction ridge analysis and genetics.[2] These resources are described as having "*high degree of confidence that would be considered beyond reasonable doubt in most legal contexts.*"[1] Interestingly, the comparative process of dental human identification has specificities. There is no protocol establishing a minimum number of AM/PM matching features, for instance.[3,4] On the contrary, what matters is that "*scientific identification using odontology normally requires comparison and matching of unique dental features*".[1] The dental features (identifiers) of interest for human identification are normally classified into morphological, therapeutic and pathological types.[5,6] According to the Best Practice Recommendation 108 of the Academy Standards Board and the Approved American National Standards, the registration of dental features should include visual examination and charting, and photographic and radiographic records.[7] The recommendation goes further regarding the PM radiographic registration: "*A complete radiographic survey of the available craniofacial remains shall be recorded*".[7]

Optimal PM radiographic registration of dental identifiers should include a full mouth series (even in regions of AM/PM missing teeth), energy adjustment for image acquisition between anterior and posterior teeth, and should reproduce as much as possible the acquisition technique of the available AM data (if any).[7] In disaster victim identification (DVI), dental identifiers are coded to feed computer-based systems, such as the KMD PlassData software (KMD, Copenhagen, Denmark) that aid with the reconciliation process.[8] What links a missing person with an existing body is the level of similarities between their dental identifiers. On other hand, what hampers an additional match with someone else is the diversity of victim's dental pattern.[9] Human identifications have the premise that dentitions are unique.[10] The rationale behind this concept is that multiple identifiers can be found on the multiple surfaces of the human teeth.[11] The combination of these identifiers and their location could generate patterns that are highly distinctive.[11] Authors have demonstrated that even a few number of identifiers, namely missing, filled and unrestored teeth, can lead to patterns as distinctive as the mitochondrial DNA.[12]

Studies performed of the last 20 years have investigated the diversity of dental patterns from radiographic data,[6,13-20] but there is no investigation pooling the samples to get a more robust perspective of the reliability of the dental patterns for human identification. This systematic review compiled existing observational studies that performed radiographic assessments of dental pattern diversity to understand to what extent the dental identifiers of different people can match.

Material and methods

Eligibility criteria

A systematic literature review was structured based on Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA). The guiding questions was: "*How diverse are the dental patterns of the human teeth when assessed from maxillofacial radiographs*"? The questions was based on the PVO acronym, in which P stands for population (human teeth), V is the variable (dental patterns), and O is the outcome (level of diversity).

Information Sources

The search was performed in October 2021, with a subsequent update search in March 2022, in the following databases: Medline/Pubmed, Scopus and SciELO. Those were primary databases for data search. Grey literature was searched in Open Grey and OATD to minimize the selection and publication bias.

Search Strategy

The strategic search was designed with Medical Subject Headings and their synonyms, combined with the Boolean Operator AND and OR (Table 1). The keywords were designed specifically using database-specific terms, including their synonyms and variations.

Selection Process

The inclusion criteria consisted of original studies on the diversity of dental patterns using maxillofacial radiographs. The only study type included was the one with observational, analytical, and cross-sectional model. The exclusion criteria consisted of 1) studies not related to the scope of this systematic literature review; and 2) literature reviews, experimental studies, editorials, letter to the editor, abstracts in scientific proceedings, books, book chapters and teaching or educational reports. Restrictions were not applied to the language, status, and year of publication.

The studies detected in the search were imported to Endnote web software (Thomson Reuters, Toronto, Canada) for the removal of duplicates. Further database-specific folders were made in the software for manual screening and removal.

Two trained forensic odontologists performed the selection of the studies supervised by a third forensic odontologist. The study selection process was divided in three parts. The first part consisted of excluding titles that were not in the scope of this systematic literature review (exclusion criterion #1). In the second part, abstracts were independently read by the examiners and were sequentially excluded if they consist of experimental studies, literature reviews, letter to editor, editorials, abstract of scientific proceeding, books, book chapters, teaching, or educational reports (exclusion criterion #2). In the third part, full-text reading was performed. In this phase, a third examiner participated to provide consensus in case of disagreement. Studies excluded in this study part had their reasons for exclusion properly registered.

Data collection

After the study selection, data collection was independently performed by two examiners. The extracted data consisted of I) the name of the authors of each study and year of publication, II) the sample size of maxillofacial radiographs, III) of the sex distribution (male, female), IV) the age range of the sample, V) the nationality of the sample, VI) the presence or not of ethical approval, VII) the type of images that were used, VIII) the radiologic equipment used, IX) the image acquisition protocol, and X) the background of the researcher. This procedure consisted of a parallel data collection where information was extracted by both examiner at the same time. Any disagreement was solved by discussion between the two examiners. In the lack of consensus, a third examiner was consulted to make a final decision.

Study Risk of Bias Assessment

The assessment of individual risk of bias and methodological quality was performed using The Joanna Briggs Institute (JBI) critical appraisal tool for use in JBI systematic reviews. The following questions were asked Q1: Were the criteria for inclusion in the sample clearly defined? Q2: Were the study subjects and the setting described in detail? Q3: Was the radiographic images analyzed in a valid and reliable way? Q4: Were objective, standard criteria used to analyze the identifiers? Q5: Were confounding factors identified? Q6: Were strategies to deal with confounding factors stated? Q7: Were the outcomes measured in a valid and reliable way? Q8: Was appropriate statistical analysis used? Two authors performed the assessment following PRISMA guidelines. Disagreements between two authors were solved by means of reassessment and discussion. Persisting disagreements were solved with the inclusion of a third examiner. Each study was categorized according to the percentage of positive answers to each of the question. High risk of bias indicated up to 49% of positive answer; moderate risk of bias ranged between 50% and 69% of positive answer and low risk of bias represented more than 70% of positive answer.

Meta-Analysis

A meta-analysis was designed to estimate the overall results, including mean, the variance of effects, and confidence interval between multiple studies that answer the same research question. In this meta-analysis, random effect model of proportions of two different grouped outcomes were used namely, different, and identical dental patterns. All the reported proportions were calculated by dividing the number of reported outcomes by the total sample used in the included studies. Then, Logit transformation was used to the measured proportion. R (version 4.2.0, R foundation for statical computing, Vienna, Austria) with metafor package[21] was used to run the meta-analysis. For each outcome, rma function was used to calculate the logit transformed proportion data. DerSimonian-Laird estimator[22] and weighted effect size were used to calculate the overall random effect model. Heterogeneity of the included study was evaluated by calculating the I^2 statistics. Additional subgroup analysis was accomplished for each arch category namely maxilla, mandible and both arches combined. All the reported outcomes were back transformed from the logit proportion to the original proportional value.

Results

Study selection

The systematic search detected 4337 studies from primary databases. After removing duplicates and excluding based on title, twenty-one studies remained for abstract reading. Twelve studies were included for full text reading. five studies were out of the scope of the systematic literature review and were excluded. Two studies entered via contribution of experts in the field along with remaining seven studies that were selected for data extraction. By the end of the study selection process, nine eligible studies were detected (Figure 1).

General characteristics of eligible studies

The studies were published between 2004 and 2021. Two studies were performed in South Korea, two studies in India, one study in Peru, two studies in Turkey, one study in South Africa, and one study in China. All the studies were published in English. In total, nine studies were presented with radiographically registered dental patterns for human identification (Table 2).

Specific characteristic of eligible studies

The sample size across studies was between 250 and 1727 radiographs. Age range was from 2.3 to 91 years (Table 2). A common factor seen between gender distribution of male (M) and female (F) is that M:F ratio is either equal or higher for females in all the studies. Four studies out of nine have reported ethical approval from their institutional committees. All the studies analyzed the diversity of dental patterns by via panoramic radiographs (Table 3). Most of the studies (75%) investigated the diversity of patterns regardless of age. Six studies (65.2%) clearly investigated the diversity rates of dental patterns from panoramic radiographs, while the remaining studies pointed out important dental identifiers that could be useful for the comparative analysis during human identifications. Morphological and therapeutic dental identifiers were predominant (Table 4).

Individual risk of bias

All studies were rated with low risk of bias. Question 5 and 6 were not applicable to the present study as there were no confounding factors to be assess in the study type selected in the systematic review. The answers of all the studies to the remaining questions were positive.

Meta-analysis

When we stratified the observational studies between different, and identical dental patterns observed in maxilla, mandible and combined arches from the meta-analysis, there was significant difference noted in the weighted proportion of different and identical dental patterns of maxilla, mandible and combined dental arches. The metaanalyses of six studies determined that the weighted proportion of different dental patterns is 0.937 (95% CI 0.889;0.965) for the combined arches (Figure 2) whereas the weighted proportion of identical dental patterns is 0.039 (0.20,0.076) for the combined arches (Figure 3). The weighted proportions of different dental patterns between maxilla and mandible were 0.897 (95% CI 0.717;0.968) and 0.924 (95% CI 0.689;0.985), respectively (Figure 2). When the dental patterns were compared between maxilla and mandible as a subgroup in the meta-analysis, the weighted proportion of the mandible has determined lesser identical patterns 0.049 (95% CI 0.018,0.127) than maxilla 0.058 (95% CI 0.013,0.217) (Figure 3). Considerable heterogeneity calculated from the I^2 was observed across studies.

Discussion

The diversity of dental patterns is an important reason behind human identification practice. This mechanism guarantees that the pattern observed in a victim could hardly repeat in other persons. This study revisited the pertinent literature, extracted data, and combined quantitative outcomes of papers into a meta-analysis to understand how diverse the human dentition is.

The weighted proportion of different dental patterns was 0.937 for the full dentition. This outcome indicates that the human dentition is highly distinctive. The diversity of dental patterns has contributed to human identification in complex cases at least for 125 years — other events have been documented, but the incident of *Bazar de la Charité* illustrates well the role of dentistry in mass disaster victim identification.[23] Accordingly, dentistry became a primary method for human identification.[2] Authors have advocated diversity of dental patterns by showing that 160 surfaces can be charted on the 32 teeth of the human dentition.[11] If restorations, caries, missing teeth are considered, for instance, there are more than 2.5 billion dental patterns possibly charted from the human teeth.[11] Our findings showed that the human dentition is not necessarily “unique” — as the literature may say.[24] This is to say that the weighted proportion of identical dental patterns was 0.039 after the meta-analysis, which suggests that identical patterns were found — even if they are in small number. This phenomenon might be explained firstly by the type of evidence that is charted from radiographs compared to the PM oral examination. All the studies selected in this systematic literature review were based on panoramic radiograph charting. On these radiographs, anteroposterior surface superimposition hampers the location of lingual and buccal restorations, for example. For this reason, only studies with a simple charting of present/absent dental features (not charting the restored surface) were considered in the meta-analysis.

When the backbone of OdontoSearch was built,[25] two systems were created — the generic one (without charting the tooth surface) and the detailed one (with tooth surfaces). When the detailed system is used, the target sample is narrowed much more because the inclusion of tooth surfaces enhances the possible combinations leading to more distinctive patterns. For example, if a person has all teeth virgin except the #36 and #46 (both restored), the algorithm could find 605 identical dental patterns (0.566%) out of a population of 107.002 individuals. If the same person is charted with teeth #36 and #46 having both occlusal-distal restoration, the search will find only 2 identical patterns (0.002%) out of the total population. Here we are talking about a reduction of the target population by 300x adding only two surfaces per restored tooth. The example provided in this step of the discussion considers the OdontoSearch system with filters off for “gender” and “race” and considers the age interval of 14-90 years and the “combined” dataset.

Another reason to carefully interpret our findings is the fact that the charting systems included in this systematic literature review and meta-analysis were not only radiograph-based (implication mentioned above), but also disregarded the type of restoration material that was used. Human identification algorithms that comply with a more detailed coding system are capable of reaching closer the true potential of the human dentitions and combined dental patterns (e.g., 2.5 billion[11]). Examples are the KMD PlassData and the WinID3 system – that include a broad variety of dental features.[26] On the contrary, experts must know that the scientific literature is robust of studies that advocate that simple and few dental features are enough to distinguish individuals.[12,25] The generic and detailed systems of OdontoSearch, for instance, can generate dental patterns from missing, filled and virgin teeth that are close to the diversity rates of mitochondrial DNA (mDNA).[12] Hence, our study corroborates these findings by showing that approximately three people could present the same maxillary-mandibular combined dental pattern out of 100 victims. In this context, it is worth mentioning that the matching patterns are mostly represented by people that have all-virgin-teeth – as this was the most common dental patterns detected across studies.

The presence of all-virgin-teeth may be related to younger individuals in the sample. Authors have demonstrated that the radiographic diversity of dental patterns increase with age, and it is more pronounced after the age of 60 years.[15] The rationale behind this phenomenon is that more alterations found in the dentition (such as the increase in the number of dental treatments — therapeutic features) will increase the distinctiveness of the dental pattern. Most of the studies in this systematic literature review assessed the radiographic dental pattern regardless of age, and those that considered age as a variable focused only on the adult dentition.[15,16] Studies with younger individuals should be encouraged to understand how the diversity of dental patterns increase from an earlier stage, when teeth are normally virgin (childhood), to a later stage (adulthood). In practice, cases with all-virgin-teeth require a more detailed search for additional features, especially those that are morphological (root shapes and bone trabeculae) and pathological (e.g. cysts, tumors). Forensic odontologists might expects cases like these when the victims are children and adolescents, or even adults from regions with low frequency of caries. Morphological and pathological dental identifiers are important even when highly similar dental features are expected, such as among monozygotic twins. The similarity of dental features between twins is regulated by genetic factors,[27] but even "identical" siblings might reveal different dentitions.[28,29] A remarkable case in the field of Orthodontics, for instance, showed discordant hypodontia among monozygotic twins (different quantity of teeth between siblings).[30] Cases that require the differentiation of twins may be uncommon in the forensic routine,[31] but they help on understanding how dental identifiers must be screened in detail in the search for distinctive features.

An interesting fact to be noticed in this systematic review is that both the mandibular and maxillary dental patterns are highly distinctive. However, the mandible presented higher rates of dental diversity (0.924) compared to the maxilla (0.897). Consequently, it is more difficult to find identical dental patterns in the mandible (0.04) than the maxilla (0.05). This outcome might be explained by the progressive decay of the permanent mandibular first molars, that emerge into the oral cavity for a longer time compared to the other posterior teeth — so they have a higher chance of being restored or missing in the adulthood (or even in childhood). In practice, the outcomes of maxilla and mandible as presented separately in this study would be beneficial to help experts to understand how reliable an identification could be if only the maxilla or the mandible are found. In both cases, experts could have high chances of finding distinctive dental patterns. The dental patterns, in this context, are built from combinations of individuals dental identifiers. Hence, a secondary outcome of this systematic review was the detection of therapeutic and morphological identifiers as the most frequently screened dental features across the eligible studies. This phenomenon may be explained by the charting systems that considered mostly combinations of virgin, restored and missing teeth, and the intention of authors to search for identifiers that are more common in practice. Therapeutic identifiers, such as restorations, are usually handmade and are tailored to each patient. So they can carry the signature of the dentist in form of different sculpting technique, materials, and colour, for instance. Morphological identifiers are mostly inherent to the patient and play an important part, especially when therapeutic identifiers are scarce.

Future studies in the field should pay more attention to the effect of age over the diversity of dental patterns. This variable could play a vital role on indicating a time threshold where dental human identification could be more robust/reliable if based only in combination of restored, missing, and virgin teeth. Experts should understand that this study is an overall screening of the scientific literature about the radiographic diversity of dental patterns for human identification and that, in practice, the diversity rates might increase because more detailed charting is used worldwide. Currently, we are able to show at least the minimum diversity rates, which are obtained from simple and few dental features – and are already highly distinctive.

Conclusion

This systematic literature review and meta-analysis showed that the human dentition is highly distinctive. The weighted proportion of the radiographic dental diversity rates reached 93.7%. Identical dental patterns, on the contrary, reached 0.03% for the full dentition – meaning that approximately three individuals could have the same dental pattern out of a target population of 100 individuals. The most common radiographic dental pattern charted across studies was all-virgin-teeth. When maxilla and mandible were considered separately, the mandible presented higher diversity rates, and consequently lower rates of identical patterns – but both dental arches were highly diverse. Authors have used a few and simple set of dental features in the charting process (such as restored, missing, and virgin teeth) – being the therapeutic and morphological ones the most common.

Declaration of interests

The authors declare that they do not have conflicts of interest related to this study.

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Legends of figures

Figure 1 – Flowchart adapted from PRISMA showing the study selection process and the number of articles that were identified, screened, and included in this systematic literature review.

Figure 2 – Forest plot of the meta-analysis showing the quantified outcomes for different dental patterns observed in the maxilla, mandible and combined dental arches for the articles that were included in the quantitative synthesis.

Figure 3 – Forest plot of the meta-analysis showing the quantified outcomes for identical dental patterns observed in the maxilla, mandible and combined dental arches for the articles that were included in the quantitative synthesis.