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SECCIÓN ENSAYOS

FORENSIC DENTISTRY IN HUMAN IDENTIFICATION: A MODERN SCIENCE

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Summary

Objectives: Forensic dentistry is a specialist branch of forensic sciences in which dental skills are put at the service of judicial systems mainly for investigative purposes for criminal acts or to identify victims of mass/natural disasters or structurally altered human remains. Its global evolution and modernization requires a comprehensive view of applications and available tools.

Materials and methods: A scoping review of the literature on this topic was carried out by consulting the main scientific databases (PubMed, Scopus, Lilacs, Google Scholar, Cochrane Library). Inclusion and exclusion criteria were established. The data were collected on a purpose-made data collection form and analysed descriptively.

Results: Studies of the applications of forensic dentistry are many and very varied. The review identified 37 relevant published articles. Some documented methods of investigation still use traditional systems of forensic dentistry while others have evolved by keeping up with the latest dental technologies. The main methods used in forensic dentistry to determine the identity of deceased or living subjects are: dental analysis useful to identify age, race and sex, cheiloscopy, bite marks, the rugoscopy, the oral autopsy.

Conclusions: Forensic dentistry plays a crucial role in many situations where other equally reliable investigations to establish the identity of a subject such as the test of DNA may be non-applicable (too altered body) or expensive (large-scale). Knowing the possibilities that a forensic dentist has to contribute to

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identification processes has a very important social and scientific aspect and value.

Clinical implications: The modern times in which we live with an international situation of huge migratory flow and frequent terrorist attacks, the findings of corpses attributable to missing subjects and other frequent crime events make professional skills and dental documentation essential for forensic purposes.

Keywords:

Forensic dentistry; Personal identification; Dental Analysis; Rugoscopy; Oral Autopsy

Introduction

Forensic dentistry (or forensic odontology) is the branch of forensic science that exploits the skills of the dentist to determine the recognition of the person, whether living or deceased, for investigative purposes or justice processes. According to the definition of Keiser-Neilsen, forensic dentistry is the discipline that "in the interest of justice deals with the proper handling and examination of dental evidence and the proper evaluation and presentation of dental findings" (1).

The expert odontologists may provide the help key to authorities by providing their expertise through dental data and informations related to them with mainly comparative methodologies in all the situations principles of forensic dentistry are applicable: mass disasters or incidents such as air plane crashes, train/road accidents, terrorist attacks, bomb blasts or natural events like earthquakes, tsunamis, land slides; in cases where a more or less wide number of human remains (especially those mutilated and dismembered) are beyond recognition; in cases of sexual assaults and/or abuse on chidren and adults; in cases of finding unknown persons for whom the attribution of an identification is necessary or in finding human remains that include the head and oral cavity or part thereof (for example, only the mandible or skull with the nasomaxillary complex but devoid of the mandible) and, not less important, in cases of malpractice and negligence in dental practice.

From the past to today the identification methods of odontologist competence have been enriched of new tools and technologies. To those of an exclusively dental nature, which mainly lead to comparative methods between antemortem data or between ante-mortem and postmortem data (in example, comparison between data collected during intraoral inspection and X-rays or

plaster models of subject of which identity is suspected) (2-4), highreliability methods such as rugoscopy (5) and cheiloscopy (6) and and bite marks (7) and oral autopsy (8) on cadaver have been associated. The latter, unlike the previous ones, for the remarkable invasiveness, being a real complex surgical procedure, plays a role as important as it is critical because, with the methods currently documented, it entails a profound alteration of the face of the subject with important ethical and legal implications (9).

The aim of this study is to offer an updated and complete review on modern forensic dentistry uses new technologies since its applications are covered in the scientific literature by groups of topics and not in order to enclose all possible existing applications.

Materials and methods

The present scoping review followed the framework proposed by Bragge et al. (11).

It comprises five steps: designing the research question; identifying relevant studies through a literature search; analysing selected studies; extracting and charting data; collating, summarising, and reporting the results. The research question was: "which activities are included in human identification processes performed by forensic odontologists?". Potentially relevant articles on the main electronic databases were searched (PubMed, Scopus, Lilacs, Google Scholar, Cochrane Library).

To be eligible for review, the articles had to meet the following criteria: abstract and full-text available, written in English language, observational studies, review articles, randomized clinical trials. A restriction of time has been applied: from 2010 to 2020. The search strategy was implemented using several search/MeSH terms like "Forensic odontology," "dental DNA fingerprinting", "age estimation from teeth", "sex estimation from teeth", "race estimation from teeth", "bitemarks", "forensic dental analysis", "ante-mortem and post-mortem dental data", "cheiloscopy", "human identification", "oral autopsy", "rugoscopy".

Duplicate results of the different databases were deleted and the abstracts of all the results have been read in order to verify that the articles were properly adhered to the objectives of the study. Articles that have not been deemed adequate since this first observation have been discarded. Doubtful articles have been retained to reserve an assessment for a full-text reading.

Each reviewer analyzed independently the articles deemed relevant for the review and evalued these informations: subject of the article (what type of application of forensic dentistry had been investigated), study type (revisions

were included), sample type (living subject/dental models, X-rays or other), important conclusions. Subsequently, these results have been analyzed in order to be able to present them in sections in this article. Additionally the scoping review was structured as a flow diagram (Fig.1).

Results

The studies of potential relevance were 667. After the removal of duplicated results (n=474), 193 articles were screened in detail, and 160 of these were considered eligible for full-text review. Of these, 37 studies published between 2010 and 2020 were included in the scoping review. The flow diagram (Fig.1) describes the entire review process.

After the full-text reading of the final articles the most relevant descriptive informations were condensed and listed in the discussion section with proper paragraphs.

Discussion

The articles gathered were divided into the groups based on the greatest interest showed in literature: dental analysis, bite marks, age estimation on dental records, race estimation on dental records, sex estimation on dental records, cheiloscopy, rugoscopy, oral autopsy. Details were presented in their following respective paragraphs.

Dental Analysis

Even though the status of a person's teeth change throughout the entire life, the presence of distinctive features (restorations, prosthetics, alterations of tooth structure including caries and the absence itself of some teeth) plays a key role when identification concerns mutilated subjects on which it is not possible to perform the fingerprint test or the visual recognition (11).

It is possible to use identification through dental analysis especially when the corpse is skeletonized or decomposed by burns, carbonization, drowning, and action of acids or other substances causing irreversible chemical damage to the body structure.

Indeed dental hard tissues are well preserved after death and can even resist a temperature of 1600°C when heated without appreciable or significant loss of microstructure. Odontological identification of deceased persons obtained by dental evidence can be complicated by traumas affected the jaws or by

inadequate ante-mortem dental records like dental plaster models and radiographs (4).

The main dental identification method is based on comparison of pre and post mortem dental features of the person under recognition process using dentist's patient documentation (3) or with photographs, available with the family, showing the subject smiling when he was still alive, although to be useful it is necessary that at least the frontal anterior teeth are clearly visible. Following the American Board of Forensic Odontology dental identification can be divided into four types (2):

1. Positive identification: ante-mortem and post-mortem data match to establish that it is from same individual;
2. Possible identification: ante-mortem and post-mortem data have few consistent features, but because of quality of the records it is difficulty to establish the identity;
3. Insufficient evidence: data is not enough to from the conclusion;
4. Exclusion: The ante-mortem and post-mortem data clearly inconsistent.In cases of insufficient evidence or exclusion, further methods are necessary.
5. When handling dentition data, the international nomenclature system is used. All salient dental features are collected and recorded to be compared with ante-mortem dental data. The presence of dental restorations or decayed teeth, the crowding and abnormal position of one or more teeth, the presence of spacing for extractions, missing teeth or natural diastema, supernumerary teeth or cusps, troot or crown configuration are all characteristic features can help in dental profiling.

When teeth fail in their eruption and remain impacted or when their eruption pathway bring them to an anomalous position (12) this phenomenon can lead to an oral status characteristic of that subject influencing personal identification process. The combination of dental and skeletal anomalies found randomly on radiographs in life can be an additional sign of individual identification (13).

As we know from basic concepts of orthodontics, the occlusion can be normal or altered both on vertical plane and on transverse and sagittal ones. The presence of a second or third class malocclusion, as well as an alteration of the overjet and overbite parameters and the presence of any anterior or posterior scissor or cross bite may represent distinctive signs of a subject.

They are almost always easily replicable even from the observation of the dentition of a corpse of which it is necessary to ascertain the identity, exceeded the stiffening phase of the body and with appropriate manipulation of the

mandible even in case of fractures. All the dental anomalies and variations mentioned above help in the comparison and matching of ante-mortem and post-mortem data leading to a positive identification. The value of this method is comparable to the quality and precision of DNA profiling and fingerprints analysis (2).

Bitemarks

A bitemark has been defined as "a pattern produced by human or animal dentitions and associated structures in any substance capable of being marked by these means"(14).

They can be classified also as examples of 'crush' injuries, due to the dental compression of the skin and soft tissues, leaving indentations or provoking a real injury in the skin (7, 15).

This action leaves indentations and/ or breaks in the skin. Bitemarks can provide evidence in those cases of sexual assaults or abuse and become a source to extract the assailant DNA (16).

The bitemark left by human teeth is classically a circular or oval mark (bruise) with central sparing. There are differences of dimensions related to kind of dentition (primary or adult) and extension of the bitemark (reduced if it's limited to a part of dental arch). Dynamic scenes reduce the clarity of the sign. Forensic odontologists are called to investigate on these marks and the classical procedure entails that bitemark is compared with impression and dental plaster of the suspect's teeth.

The aim is to identify adequate correspondence between the main shape and size of the teeth of an accused with the features of the bitemark. All those distinctive features of dentition such as dental malposition, crowding, missing or damaged teeth can affect the bitemarks and they can be reasonably considered reference points in the comparative analysis (15).

Traditionally, the comparison between the bitemark and the suspect's teeth was based on the superimposition involved the occlusal surfaces of a dental model of the suspect's teeth, specially stained on ink, and marking the teeth 'bite' pattern onto a transparent sheet (in acetate). With the advent of new technologies, the limits of this procedure, which have always been discussed and looked at with a certain distrust in the forensic field, have been partly overcome thanks to software that allows the digital overlap of the bitemark photos to digital models (16,17).

Age estimation on dental records

The problem of age estimation does not concern only unidentified corpses but above all living persons have no valid proof of date of birth (18). We can distinguish two main methodological categories in dental age estimation (19):

1) Developmental changes: occur while teeth are growing and emerging into the oral cavity. They include hard tissues changes, dental eruption and the specific third molar eruption and dental measurements.

2) Degenerative changes: occur once teeth have erupted and begin to wear down. Developmental changes related hard tissue modifications start since teeth start their formation, around six month. The exact sequence of formation and eruption of teeth allows to accurately estimating age. The basic principle is the comparison between teeth scores and a corresponding chart, such as in the famous Demirijan's method (20).

The comparison between post-mortem radiographs of a person under personal identification process and eruption standards lead to the estimation of age, since humans have two stages of dentition, and a mixed stage. Third molars are the last teeth to erupt and also those with the highest variables: they can be partially or at all impacted and their missed eruption after 20 years old can indicate they are absent at all. Only radiographs can reasonably show their presence, position and relations with the adjacent structures. Dental length can be directly assessed, using the crown or the exposed root and then compared with radiographic measurements. Dental mineralization is less affected than bone by nutritional and endocrine factors (21).

Once teeth erupted and begin to perform their masticatory and functional functions, they obviously begin to undergo alterations accompany the progress of age with signs that can be very characteristic. One of the most characteristic examples of degenerative changes is the observation of the pulp volume that reduced progressively with aging for a process of secondary dentin deposition (22).

Another method of age estimation in adults by measuring the size of the pulp is taking the measurement from periapical radiographs of the teeth dependent upon the sex of the individual (23).

The most complete method of age estimation based on regressive changes has been developed pimarily by Gustafson, and later by Johanson. These methods consider changes affect teeth for the occlusal attrition, the loss of periodontal attachment, the dentine and cementum apposition, the amount of periapical resorption, the root transparency (24, 25).

Sex determination on dental records

Sex determination is the first question in identification of unknown individuals, especially when other evidence for sex determination is present. As for the other distinctive features defining and detailing the individual, this parameter often need to be confirmed with the help of many methods, because sex determination from teeth may be not conclusive. Sex determination in forensic odontology starts from odontometrics'technique (26).

This is based on the differences between the mesio-distal and bucco-lingual dental dimensions, recorded like linear multiple measurements that are subsequently compared (27).

Sexual dimorphism in the teeth can be showed using different dental indices: crown index, incisor index, mandibular-canine index. This last index is considered one of the more reliable in sex determination since these teeth exhibit a greater sexual dimorphism compared to upper canines with an overall accuracy established around ~72%. The canine distal accessory ridge located on the lingual surface (between medial lingual ridge and distal marginal ridge) has been found to be more pronounced and more frequent found in males than females (28).

In the last years a laboratory method has been developed: the sex chromatin or Barr bodies extracted from the pulp help in sex identification. The Amelogenin, called also "AMEL", is the major protein found in human enamel. Two different genes express for AMEL: one is located on chromosome X and one on the Y chromosome. The patterns of nucleotide sequence show differences in males and females (29).

Amelogenin has different patterns of nucleotide sequence in the enamels of males and females (30).

Race determination on dental records

Race or ethnicity determination from dental characteristics is still subject to debate today. Indeed there are dental traits that may be characteristic of some populations but their influence on racial individual identity is critical and needs to be supported by other elements.

Some dental characteristics are mostly referable to habits, activities or related to the environment in which an individual lives, so they can be referred to ethnicity only secondarily and by deduction, finding a relationship between that dental characteristic and that particular ethnic group. This consideration is more evident for the shovelling or scooping of the upper incisor (most common in Asiatic Mongoloids and Amerindians), chisel shaped incisors (31).

Other features such as taurodontism, peg shaping of the teeth, Carabelli's cusp of the first upper molars, hypocone, and protostylid, are used to determine the racial profile but their power in this meaning is much more weak than other parameters. The provenience of an individual, more than a specific ethnicity, may be in some cases indicated by dental restoration features, because some methods or materials may be typical of a place.

Cheiloscopy

Labial wrinkles have same value as fingerprints, this is the reason why cheiloscopy is a valid forensic investigation add evidence to a crime scene, in example on glasses, windows, cigarette butt, or tapes (if a person has been gagged or bound), especially when other evidence are weak or totally absent. The lip prints indeed can be easily left on many surfaces where they pressed up against.

There are four types of lip grooves: straight line, curved line, angled line, sine shaped line (2). Lip print patterns often appear as a mixture of varying types even though we can distinguish five main pattern: vertical, partial vertical, branched, intersected, reticular. There is a probable genetic inheritance since twins and family members showed similar grooves (32). The lip print pattern is unique to each individual and remain unaltered during a person's lifetime.

They can be altered by pathologies or environmental factors but only those events or pathologies affect the labial subtrack can irreversibly damage lip prints, in light traumas or not severe pathologies they use to repair without any change and to maintain their pattern. Lip prints similarly to finger prints may be visible or not visible. Many reagents can be used to make latent lip prints visible (33). Lip print analysis is very simple and not expensive, but the absence of a standard protocol to collect, record and analyse lip prints data reduce their judicial value as test document (6).

Rugoscopy

The use of palatal rugae for forensic purposes started in 1889 with Harrison Allen, but the name of "palatal rugoscopy" has been properly introduced later, in 1932, by Trobo Hermosa. Then many classifications followed in the years, according to different features like shape, direction, position, length, unification.Palatal rugae is relevant for human identification due to the internal position, stability and maintainance after death (34).

Palatal rugae also called as rugae or plicae palatinae refers to the transverse ridges on the anterior part of the palatal mucosa on each side of the median palatal raphe and behind the incisive papillae. They are three to seven in number and the variability is the main feature of their uniqueness. Rugae pattern is as unique to a human as are his DNA or fingerprints and since their formation during the 12-14th week of prenatal life pattern's structure remain unchanged throughout life not altered by diseases, traumas, heat and chemicals uptaken during life (food, nicotine, dugs, ethanol, etc.). Due to stability palatal rugae is considered a reliable landmark during orthodontic treatments, cleft palate surgeries, palatal prosthesis and medicolegal evaluations (35).

The palatal rugae position is designated as left/right to determine which quadrant they belong. Rugoscopic area can be divided into quadrants, with the aim of obtaining the coordinates position of palatal rugae. Rugae length is the first information need to be assessed. Three categories can be distinguished: primary rugae (5-10 mm); secondary rugae (3-5 mm); fragmentary rugae (2-3 mm); rugae measuring <2 mm are not considered. After length, usually the shape is assessed.

Transversely, for each palatal rugae starting from the mid-palatine raphe, we can individuate the medial point, and adjacent teeth, we can individuate the lateral point. Ever transversely we can classify four major types of shapes: circular, curvy, sstraight, wavy. Adding other shapes we can classify ten major types: angle, anomaly, bifurcated, circle, curve, interrupted, line, point, sinuous, trifurcated (36) (Fig.6).

The palatal rugae direction is determined by measuring the angle formed by the line joining its origin and termination and the line perpendicular to the median raphe. Based on direction rugae can be classified in: Forward directed ;Backward directed; Perpendicular.

Another feature can be assessed in palatoscopy is the presence of unification, occurred when two rugae joined at their origin or termination. Traditional and still valid palatal rugae analysis is made on maxillary dental plaster models using cheap tools: pencil, caliper (if possible a digital one), magnifying glass. The general method is strictly comparative. The use of direct inspection and comparison with photographs proved to be unsuccessful and this method was abandoned.

The development of experimental softwares for photographic superimposition (i.e. RUGFP- Id, Palatal Rugae Comparison Software) introduced oral photographs again as alternative source to plaster models (5). Nowadays stereoscopy and stereophotogrammetry allow 3D analysis and comparison of dental models. Palatal rugae patterns have been largely studied to evaluate if

they are a reliable forensic marker for sex determination(34, 35), epidemiological traits (35, 36), and their stability after different orthodontic treatments (37).

The most of the rugoscopic studies found in literature have been performed on dental casts and living persons. One study in literature analyse palatal rugae stability in cadavers and burn victims using a visual inspection and photographs without a real personal identification purpose (38).

The most recent study evaluates the stability of palatal rugae in cadavers by superimposition of digital models obtained using an intraoral scanner on the day of death and after one week (39).

Oral autopsy

Usually, forensic dentists participates in personal identification processes helping in establishing the age, sex, and race of corpses or skeletal remains. The sources are teeth, bite marks, lip prints, palatal rugae. The forensic dentist can use radiological examinations and post-mortem dental records, all as described so far. Oral autopsy may help in cases where dental evidence is almost mandatory and intra-oral examination cannot be accurate or possible at all due to a poor accessibility (40).

This problem is not rare especially when the conservation of body is critical or when remains are uncompleted and the identification process risks to be retarded. Intra-oral examination is easier when traumas and injuries affected face and oral region. Oral autopsy helps to register teeth present in the oral cavity, the type of occlusion, and the presence of ante-mortem dental restorations.

The age of the person influence oral autopsy operations: in adults often is necessary to operate with jaw removal and skin and muscle dissection, especially when rigor mortis closes the access to a clear observation of the mouth; the muscular weakness in children makes this procedure less complicated.

Teeth or their germs can be extracted and age estimated by light microscope studies or scanning electron microscope. In presence of deciduous teeth, age estimation is simpler. In cases of criminal abortions, mass disasters, abandons and miscarriages the oral autopsy of foetuses and infants is such important as more complicated than children or adults.

The procedure of oral autopsy ever starts with frontal and lateral photographs of the face's corpse and then follow these steps (8): incision from the angle of the mouth to the tragus of the ear on either side; folding of lip and cheek tissues; sectioning of the muscles and the capsular ligament of the temporomandibular joint; opening of the mouth by traction that allows visualization of the lower and upper dental arches; photographic records of the

oral cavity; removal of prosthetic and orthodontic appliances if present; charting of the mouth in the postmortem dental record; description of the anomalies of shape, position, and size of the teeth; taking of adequate photographs to compare with ante mortem records; suturing.

Some autopsy procedures deviate from this method with regard to the surgical incision that can take place below the mandibular plane, keeping intact the appearance of the skin tissues and muscular planes. Oral autopsy procedures regardless of the surgical methods used to expose the oral cavity are always very invasive. It is a vilification of the corpse, both on the ethical level because the family of the deceased is put in front of a further pain that is added to that of the loss of the loved one. A recent study proposes to overcome the limits of traditional oral autopsy using the intraoral scanner that allow to maintain facial integrity by obtaining color images of dental arches even in condition of limited access and to superimpose the 3D reconstructions on traditional ante-mortem radiographs (39).

Conclusions

The teeth and the oral structures have individual characteristics that make each individual unique and unrepeatable. Where the other means of identification are destroyed, deeply altered or voluntarily removed (fingerprints can be deleted) or when the use of other techniques would be wasteful because it is necessary to apply them on a large number of subjects (DNA analysis is more expensive), the oral cavities are the strongest part of the human body withstanding the most serious chemical and physical injuries. Primary and adult human dentition vary in morphology, size, volume and sometimes structure among different individuals constituting the basic set of unique characteristics called "tooth class characteristics" for identification. Other features like restorations, prosthesis, dental pathologies and anomalies contribute to defining the "dental identity".

From teeth, we can estimate the biological profile and determine the age, the gender, and the ethnicity. The evidence in forensic dentistry is obtained also with no dental records as rugoscopy, cheiloscopy and oral autopsy.

These methods should not be considered to be less precise than the dental analysis, but should also be considered as complementary to the identification or altogether essential (especially for the rugoscopy) when dental analysis it is not a conclusive or workable test.

All these characteristics however, may not be useful to the forensic processes in absence of ante-mortem dental records and where comparison of

the post-mortem records with ante-mortem records is not possible. For this reason it would be necessary and of great importance to hope for the preservation of data and the creation of a "dental" database as well as the communities of the different countries already have it for fingerprints.

Clinical implications

Forensic dentistry has long been considered by professionals as an activity often far from daily clinical practice, with a destination mostly related to the insurance system.

The rich scientific production on the topic of personal identification, more closely connected to the judicial activities of recognition of the person, demonstrates how the role of the dentist, sometimes even occasionally given to forensic sciences, can be decisive.

The ability to understand and interpret the distinctive features of a subject from his or her oral cavity, the possibility of consulting for comparative purposes the radiographic and digital information, consulted daily for diagnostic and therapeutic objectives, even in extraordinary situations makes the dentist a modern operator much closer to forensic medicine than is believed possible. Starting from this awareness, the modern dentist, when required, must with the same sense of responsibility with which he carries out his clinical activity, make his skills, and where necessary, the data of his archive available to the competent authorities, becoming an active part of the team which seeks to solve the social and judicial problems of the society.

Conflict of interests

The Author have no conflict of interests.

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