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CONTENTS

RESEARCH

REVIEWS

OBSERVATIONS ON DENTAL PROSTHESES AND RESTORATIONS SUBJECTED TO HIGH TEMPERATURES: EXPERIMENTAL STUDIES TO AID IDENTIFICATION PROCESSES

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ABSTRACT

In large scale disasters associated with fire the damage caused by heat can make medico-legal identification of human remains difficult. Teeth, restorations and prostheses, all of which are resistant to even quite high temperatures can be used as aids in the identification process. In this project the behaviour and morphology of teeth and dental prostheses exposed to a range of high temperatures was studied.

Healthy teeth, dental restorations and prostheses were placed in a furnace and heated at a rate of 30°C/min and the effects of the predetermined temperatures 200, 400, 600, 800, 1000 and 1100°C were examined by stereomicroscopy and scanning electron microscopy (SEM). Our observations show that some prostheses and restorative materials resist higher temperatures than theoretically predictable and that even when a restoration is lost because of detachment or change of state its ante-mortem presence can be confirmed and detected by both stereomicroscopic examination and SEM of the residual cavity. We further conclude that a reasonably reliable estimation of the temperature of exposure can be made from an analysis of the teeth and restorative materials. **(J Forensic Odontostomatol 2002;20:17-24)**

Keywords: Identification, forensic odontology, dental materials, dental prostheses, dental restorations

INTRODUCTION

Forensic dentistry has been shown to be of fundamental importance[1] in medico-legal investigations aimed at identifying human remains of mass disasters involving high temperatures.

One of the first studies on identification of human remains by dental examination goes back to 1897 and was carried out following the fire at the Bazare de la Charité.[2] This study laid the basis for the awareness that the morphological features of the oral cavity e.g. changes associated with age, developmental disorders, pathological conditions and a number of dental interventions, are numerous and varied enough to constitute a unique and non-recurring picture. Furthermore, both teeth and dental interventions have a large number of features each of which, alone or in combination, can contribute to a positive identification.

While 16-18 matching elements are usually required for a positive identification by fingerprint analysis, an appropriate number of comparison features for dental identification has not yet been established, precisely because of the enormous number of possibilities. A minimum of 12 points of correspondence has been suggested in order to make a positive identification,[3] but Simpson *et al*.[4] emphasized the importance the qualitative aspect of a finding has compared with a quantitative value and that, in consequence, some characteristic forms of dental treatment must be considered highly significant.

The temperatures reached in many fires vary depending on the site (in a closed environment or in the open), the nature of the oxidant, the duration of the combustion, and the action of any fire-extinguishing products used.[5,6] Indeed, it has been found that in road traffic accidents, strong ground winds and the 'chimney stack effect' of piled up car wrecks can raise the temperature of combustion of petrol to above the known mean range (800-1100°C).[7]

Teeth are skeletal components that readily survive severe fires, not only because of their particularly resistant composition, but also because they are protected by the soft tissues of the face and other materials or elements sometimes present (e.g. glasses, crash-helmet) which cause a delayed and different increase in temperature in the oral cavity,[8] although this effect decreases as the "protection" burns.[9]

Finally, it has been noted that the dental remains of victims of some air disasters associated with fierce fire have many dentinal and enamel fractures which are different from and more numerous than those found in road traffic accidents. It has been hypothesized that this phenomenon is caused by a combination of high temperature and impact force, but this is still under investigation.[10, 11]

Besides direct visual inspection of the dental remains, radiographic examinations are very important in order to reach an identification. There are, however, two problems in carrying out radiography of maxillary or mandibular fragments: the lack of soft tissues often leads to overexposure and, given the absence of the cranium, it is difficult to achieve correct alignment of the fragments.[12]

Optical and/or electron microscopy of the dental parts can be useful for two main reasons: to identify the changes the dental tissues have undergone in order to estimate the temperatures they were exposed to and, furthermore, to characterize the different types of dental treatments.[13]

Dental identification is traditionally based on the comparison of the odontogram and/or dental record of a known person with that reconstructed from human remains and it is essential that there exists an ante-mortem record. It is important to emphasize that radiographic investigations can provide unique and characteristic information on individual anatomy even in the absence of dental treatment.[14] For this reason the Defense Department of the U.S.A. has catalogued the orthopantomographs of all recruited military staff. These images are stored in specific archives and retained when the person leaves the armed forces.[8]

Dental prostheses, besides being of great help in personal identification (from analysis of the type, shape, size, surface features, etc.), can also provide information on the country of manufacture, by analysis of the materials used. This was clearly described in a recent article by Marella and Rossi1[4] who described various factors that can negatively affect the tracing of components of prostheses. The presence of environmental debris and/or products of previous casting, mixtures of metals or traces of elements not registered by the manufacturer may affect the identification of the components of the prostheses.

In this context we considered it important to carry out an experimental study to learn more about the changes that dental remains, restorative materials and prosthetic devices undergo when exposed to a range of temperatures, with the aim of advancing the knowledge base used in the processes of identification of victims involved in fires.

MATERIALS AND METHODS

Various specimens were used for the study: (1) one healthy, unrestored tooth, (2) one molar with one previously existing class I restoration in amalgam and one added class V restoration in amalgam (Valiant*) (specifically carried out for the research), (3) one premolar with a class V restoration of the vestibular surface in composite (Spectrum T.P.H.© **), and one with a class V restoration of the lingual surface with compomer (Dyract AP© **), (4) one fixed prosthetic crown or bridge of aesthetic resinous material (polycarbonate, acrylic based products or composite materials),*** (5) one fixed prosthetic crown or bridge of metal alloy covered with aesthetic resinous material (acrylic based products or composite materials),*** (6) one removable partial prosthesis made of base metal casting alloy and denture base acrylic resins,*** and (7) one fixed prosthetic crown or bridge in metal-feldspatic ceramic dental systems.***

After extraction, the teeth were preserved in normal saline at room temperature for one week. Some of the amalgam fillings in the teeth extracted were old while other restorations such as the class Vs with composite and compomer material were done deliberately for the experiment.

The tests of exposure to heat were carried out in a preheating oven (CF4),† and the specimens were heated to one of the six pre-determined temperatures - 200, 400, 600, 800, 1000 and 1100°C, at a rate of increase of 30°C/minute. As soon as each target heat had been reached the samples were removed from

* *Caulk-Dentsply, Milford, DE, USA.*
** *De Trey Dentsply, Kostanz-D.*
*** *undefined production samples resulting from extraction therapies at the Dental Clinic.*
† *Dentalfarm, Turin, Italy*

the oven and allowed to cool to room temperature. The total time of exposure for each set of specimens was 6,6 mins to reach 200°C; 13,3 mins to reach 400°C; 20 mins to reach 600°C; 26,6 mins to reach 800°C; 33,3 mins to reach 1000°C; 36,6 mins to reach 1100°C. About 10 secs were needed to remove the sets of samples from the oven.

Two complete sets of specimens (groups one to seven) were each subjected to each temperature and 108 observations were made (groups two and three each had two restorations to test). The source of specimens in groups four, five, six and seven, was from the Exodontic Clinic, but in compliance with the rules concerning medical and dental devices in force in Italy and contained in the CE directive 93/42, the materials used have to be standardised. In effect then, for these specimens it was not possible to define the exact composition, but it was possible to assign them to known groups of compounds or alloys: group (4): polymer-based crown and bridge materials;[15] group (5): dental casting gold alloys or dental casting alloys with noble metal content of at least 25% but less than 75%[16]; group (6): dental base metal casting alloys: cobalt-based alloys or nickel-based alloys;[17] group (7): metal-ceramic dental restorative systems[18]. Some metallic devices showed a welded portion which involved brazing materials and alloys whose general composition complied with the Standard.[19] Since the sample collection was difficult because of the great number required, it was impossible to standardize the dimensions of the restorations found in extracted teeth, or the prostheses encountered. All of them were in any case of sufficiently useful dimensions to give reliable data. The restorations created for the project were about 6^3mm in volume (3x2x1 mm.).

Each sample was examined macroscopically and then observed by stereomicroscopy* and SEM† after gold metallization.

RESULTS

The macroscopic and microscopic findings for each specimen at different temperature levels were as follows:

1. Intact teeth:
   200°C: there was a macroscopically evident change of colour, tending to yellow/light brown, of both the root and the crown; stereomicroscopic examination revealed microfractures of the root.
   400°C: the surface colour of the enamel tended to grey whereas that of the cementum and dentine ranged from black to brown; stereomicroscopy (32X) showed cracks and fissures not only in the root but also on the enamel surface.
   600°C: macroscopic evaluation showed black discolouration of the whole tooth, a shattered part of the crown and detachment of the enamel wall from the underlying dentine. Deep cracks were evident in the root.
   800°C: the crown had shattered into pieces whereas the root remained whole. The surface colour of the tooth was chalky-white while its interior was grey-blue. The cracks in the root were more marked.
   1000°C: the crown was reduced to fragments while the root, still whole, was pinkish-white with deep cracks and numerous microfractures; what remained of the pulp cavity appeared greyish-black.
   1100°C: macroscopic observation showed the crown reduced almost to dust and the root portion shattered. The larger fragments were chalky-white with some areas of a pinkish shade and, coinciding with the cementum, a grey colour was seen.

2. Class I and V amalgam restorations of molars:
   200°C: the marginal seal of the class V filling (carried out 24 hours previously) was maintained perfectly, while that of the class I filling (*in situ* for several years) demonstrated slight retraction and with both there were bubbles indicating separation and subsequent evaporation of mercury.
   400°C: macroscopically both the class I and V fillings were in place, although both showed the same phenomenon noted at 200°C, that is the presence of bubbles on the surface. The fact that the fillings had remained in place despite the teeth being fractured in various ways, with the separation of large portions, is an indicator of only modest marginal retraction. Stereomicroscopic observation (32X) revealed enamel

* *Carl Zeiss Italia, Milan, Italy.*
† *Cambridge Stereoscan MK2*

microfractures. The surface of the tooth beneath the amalgam restoration, examined by SEM (1100X), showed the presence of dentinal tubules.
600°C: there was macroscopic detachment of the class I and V restorations. The shape and size of the restorations appeared to be unaltered. Stereomicroscopy (20X) revealed the grooves in the residual cavity produced by the cutting instruments (Fig.1); it was possible to detect metal residues of the amalgam on the root surface. SEM of the dentinal surface below the cavity showed deep cracks and fissures.
800°C: the coronal part of the teeth had shattered and the amalgam fillings were recovered at some distance from the teeth in a partially melted state, altered in both shape and structure (Fig.2). The parts of the cavity that had contained the filling could be identified in the largest fragments of the crown and, particularly by stereomicroscope (20X), signs of the milling instrument were evident.
1000°C: the dental crowns had disintegrated completely and it was possible to recover amalgam residues. The remaining parts of the teeth appeared chalky-white with pink shades both near the class V cavity and in the root bifurcation; the metal residues of amalgam had moved. SEM (1200X) of the dentine below the amalgam restoration showed an irregular surface in which it was difficult to identify tubules.
1100°C: macroscopic examination showed bits of teeth fractured into numerous chalky-white and grey fragments, although in the area of the root corresponding to the cementum there was still some pink staining. The amalgam restorations were partially melted although some fragments could be recovered. Again at this temperature some deposits of metallic matter could be detected on the root portion of the tooth.

3. Premolars restored with composite and compomer:
200°C: no macroscopic changes in colour but modest marginal retraction was noted. Stereomicroscopy (20X) showed a loss of the marginal seal.
400°C: the composite restoration had detached and, although remaining whole, had undergone a change in colour to yellowish-brown; the same colour changes were seen in the compomer fillings but these had remained *in situ*. Stereomicroscopic (16x) and SEM (510x) examination of the cavity containing the composite fillings showed the surface markings caused during the preparation of the cavity (Fig.3).
600°C: there was no trace of the composite or compomer restoration: the almost black dental tissue was crossed by deep fractures and it was possible to identify only part of the preparation of the cavity on the vestibular facets. Stereomicroscopy (32X), revealed the characteristic grooves of milling while SEM (1200X) of part of the dentine underlying the composite filling displayed dentinal tubules and a deposit of well-defined shape that was probably the charred remains of the restoration (Fig.4).

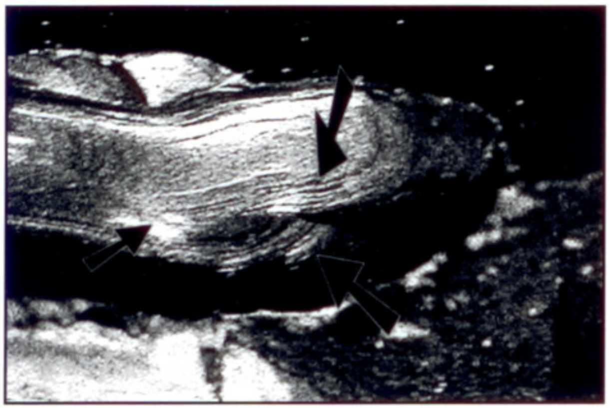

***Fig.1.** Stereomicroscopic image (20X) of the V class cavity (of an inferior molar restored with amalgam) after exposure to heat up to 600°C. The grooves produced by the instruments during the preparation of the cavity can be identified (arrows)*

***Fig.2:** Stereomicroscopic image (20X) of a class I amalgam restoration recovered at a distance from the residual dental fragments after exposure to 800°C. The amalgam is in a partially melted state, altered in shape and structure and with a piece of dental tissue attached*

Fig.3: *SEM image (510X) of a cavity prepared for repair with composite after exposure to 400°C. The marks caused by the bur during cavity preparation are visible*

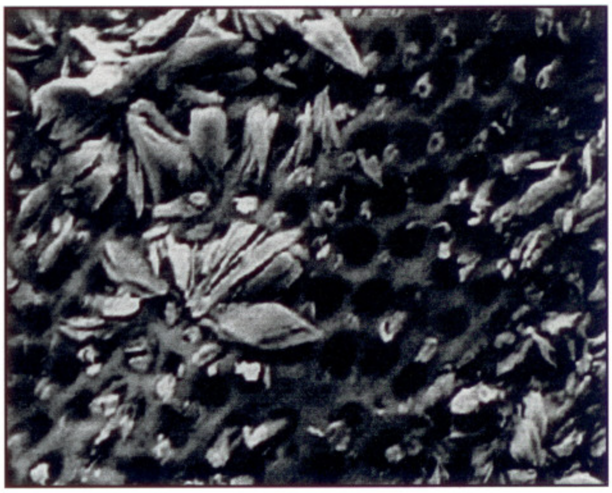

Fig.4: *SEM image (1200X) the floor of a cavity prepared for the filling with composite material after exposure to 600°C. The dentinal tubules and a deposit of solid material, probably a residue of the incinerated composite, can be identified*

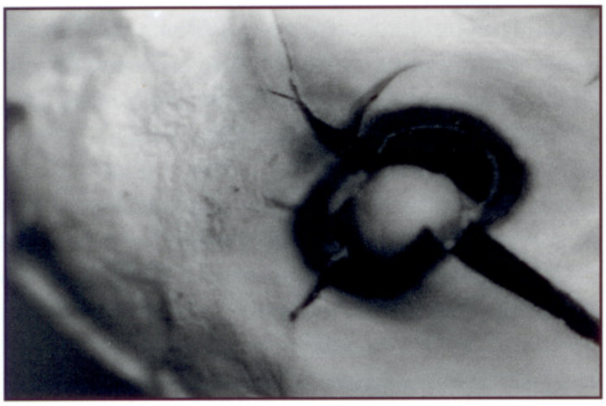

Fig.5: *Stereomicroscopic image (16X) of a fragment of root after exposure to 1000°C. Occasional finding of an endodontic filling material in a premolar repaired with composite and compomer after complete shattering of the crown*

Fig.6: *Stereomicroscopic image (20X) of a bridge covered with acrylic resin after exposure to 400°C. There is partial degradation and loss facing material. The alloy shows the first signs of oxidation with discolouration*

800°C: there was macroscopic shattering of the crown while the roots remained whole and whitish-blue. It was possible to identify the prepared cavities but not residues of the restoration.

1000°C and 1100°C: the crowns of the repaired teeth had completely disintegrated; only fragments of root showing numerous cracks and microfractures remained. An occasional finding of an endodontic filling material in one sample was observed after the complete shattering of the crown (Fig.5).

4. Fixed prosthetic crown or bridge made of polycarbonate, acrylic based products or composite materials:

   200°C: macroscopic observation showed minimal surface changes without loss of substance.

   400°C: the resin showed early signs of flow with loss of material while the residue of the bonding material within the crown remained almost unaltered.

   600 – 1100°C: it was not possible to detect any trace of the acrylic resin.

5. Fixed prosthetic crown or bridge made in metal alloy covered with aesthetic resinous material (acrylic based products or composite materials):
   200°C: direct observation and stereomicroscopy (16X) showed slight retraction of the resin component.
   400°C: macroscopic examination revealed partial degradation and loss of substance on the facets of the aesthetic material (acrylic resin based product or composite material). The alloy showed early signs of oxidation with discolouration (Fig.6).
   600°C: the loss of the resinous component (acrylic based or composite material) could be appreciated macroscopically while traces of the bonding system used at the alloy-aesthetic material interface (silane) could be seen on the surface of the alloy (which remained intact) (Fig.7).
   800°C: there were obvious changes in colour caused by the oxidation of the metal alloy. All the aesthetic material had disappeared.
   1000 – 1100°C: the metal structures had retained their original shape, the bonding cement was still present within them and there was some initial melting of the alloy.

6. A removable partial prosthesis made of base metal casting alloys and denture base acrylic resins:
   200°C: there were no macroscopically evident changes in the alloy while the resin bases and the prosthetic teeth were soft on removal from the oven. Once cooled the colour and shape of the teeth were altered whereas the resin bases retained their original properties.
   400°C: macroscopically the teeth did not differ from those examined after exposure to 200°C, while the resin bases were completely burnt, leaving charred remains.
   600°C: the resin components were no longer detectable and the metal alloy was oxidized. Stereomicroscopy (8X) revealed the casting flaws in the metal.
   800°C: macroscopic examination showed the typical colour change caused by oxidation of the alloy.
   1000°C: there was a macroscopically visible increase in surface oxidation and the areas in which overcasting had been performed during the production of the device were more evident (Fig.8).
   1100°C: the oxidation was more marked but the structure retained its shape almost unaltered without structural collapse or loss of material except in some areas in which reorganization of the alloy showed internal bubbles formed at the time the device was manufactured.

7. Fixed prosthetic crown or bridge in metal-feldspatic ceramic dental systems:
   200°C: there were no macroscopically evident changes in the shape or colour of the crowns.
   400 - 600°C: there was a macroscopically visible slight colour change.
   800°C: the porcelain surfaces were slightly rough

Fig.7: *Stereomicroscopic image (8X) of a bridge covered with acrylic resin after exposure to 600°C. The loss of the facing can be seen while traces of the bonding system used at the alloy-facing material (silane) interface can be found on the surface of the alloy which has remained intact*

Fig.8: *Stereomicroscopic image (8X) of the metal structure of a removable partial prosthesis after exposure to 1000°C. There is increased surface oxidation and in particular, as a result of the flow of the soldered alloy in the areas which were superfused during the preparation of the device*

and porous and had undergone a mild change in colour.

1000°C: macroscopic observation showed splintering and loss of substance of the porcelain covering and bubbles on the surface and the alloy remained unaltered.

1100°C: the porcelain coverings showed the effects of early softening, with surface cracks, while it was still possible to find traces of the bonding cement inside the metal structures.

DISCUSSION and CONCLUSIONS

Our experiments show that dental tissues, prosthetic devices and restorative materials undergo a range of changes which correlate well with the various temperatures to which they were exposed. These changes are a consequence of the nature of the materials and their physicochemical characteristics, but individual components can remain recognizable and identifiable even at very high temperatures. For example, at 1100°C it was possible to recover and identify residues of amalgam restorations while the prostheses in metal-porcelain contained residues of cement (which obviously had not been directly exposed to heat since it was protected by both the porcelain and the alloy). At the same temperature the teeth were well recognizable and not completely destroyed thanks to their mineralized structure. Our experiments did not take into account possible factors present in real-life circumstances, described in the introduction i.e. the protection afforded by soft and hard tissues surrounding the dental components and/or devices, nor any other externally worn items. For example, the root of a tooth should be even more resistant to thermal insults since it is sheltered within the bone. These *in vivo* circumstances prevent direct exposure to fire which would otherwise almost always cause violent evaporation of organic components with consequent explosion of the crown. This phenomenon occurred in our experiments starting from a temperature of 800°C. Incineration of soft tissues and any other organic material can produce a metallic-coloured layer covering the teeth which can modify the real colour change. It is therefore very important to carry out SEM and stereomicroscopic analyses in order to identify the real presence of restorative materials, particularly when only fragments of the teeth remain available for analysis as an example the occasional finding of an endodontic filling material in a premolar repaired with composite and compomer after complete shattering of the crown was observed with the stereomicroscope (Fig.5). Furthermore, amalgam releases mercury vapour which reacts readily in the presence of gold or alloys, further causing colour changes to the tooth; this occurred in our experiments starting at a temperature of 400°C.

At a temperature of 200°C the teeth did not show signs of fractures. As the temperature rose, cracks, fissures and fragmentation of both the crown and the root occurred, although in two cases, at 600 and 800°C, the teeth fractured when handled. This highlights two important points: first, that calcined teeth, being completely dehydrated, are very delicate, and secondly, that fractures may precede the fire because in real-life situations trauma is often associated with the high temperatures caused by major fires.

In our experiments, once the desired temperature had been reached, the specimens were removed from the oven and left to cool, thus all the materials were exposed to a single, brief, thermal insult, whereas in reality various factors can further modify recovered remains: the duration of the exposure to fire, the way in which the fire develops, the rate of increase of temperature, and substances used to extinguish the fire.

We conclude from our experiments that:

(1) some prosthetic devices and restorative materials seem resistant to temperatures higher than those theoretically predicted, for example the glass transition temperature of pure poly(methyl) methacrylate is 120°C[20] but in our experience the facing acrylic material of the bridge (group 4) (Fig.6) was only partially altered after exposure to 400°C while the base portion of the removable partial prosthesis (group 6) showed at 200°C, only a softening of the acrylic. This may be explained by differences in composition and in processing;

(2) when a restorative material is lost because of detachment or change of state, its prior presence can be detected by both SEM and stereomicroscopy of the remaining cavity and its surface morphology;

(3) it seems possible to reach a reasonably reliable estimation of the temperature of exposure from an analysis of the teeth and restorative materials.

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FRAUDULENT USE OF RADIOGRAPHIC IMAGES

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ABSTRACT

The aim of this study was to evaluate the ability of trained observers to identify altered radiographic images after modifications using an image-editing software. Based on implantology in 10 radiographs, eight panoramic and one linear tomograph were modified while one tomograph was untouched. Implants were placed or removed and bone levels were altered, and seventy dentists were invited to identify these alterations. The results showed that the percentage of the correct answers was 12.5% or 2 identifications per examiner. The rate of false positives in relation to correct answers was at a level of 6:1. We concluded that the professionals have difficulty in identifying altered radiographs after using an image-editing software and that the seriousness of this situation demands that dentists be warned of the dangers of the use and abuse of this technology. **(J Forensic Odontostomatol 2002;20:25-30)**

Key words: dental radiography; radiographic image enhancement; forensic dentistry

INTRODUCTION

Radiography is an important tool to dentists as it provides valuable information about internal dental and bony tissues, which would be inaccessible through clinical examination. It is therefore considered as the main, and sometimes the only means of exploring the details of a subject's jaws, including given treatment, and is useful when legal aspects regarding dentistry are considered.

Advances in radiographic technology have now led to digital imaging, first as the indirect method through digitized film and subsequently as the direct method, where digital sensors are substituted for film. The many advantages of digital radiography have led to a wide acceptance of this method by professionals, in agreement with some authors [1-3] who believe it has great potential for use in the clinical routine, doing away with the radiographic film within the next decades and on through the improvement and cost reduction of the digital systems.

The legal implications of digital radiography are however to be considered. Some authors have emphasized the seriousness of this issue,[4-8] and agree that the original image can be altered when image-editing software is used. Diagnosis, prognosis and treatment plans can be completely modified in accordance with legal interests and in order to disguise iatrogenesis. Such alterations can be done specifically in an area of interest in the original image, by adding, subtracting or disguising dental materials, pathologies or even anatomical structures.

As a result of the rapid growth of implantology where some non-skilled professionals practise this speciality, and the resulting occasionally dissatisfied patients who have instituted lawsuits, we decided to undertake the present study in order to evaluate professionals' ability to identify altered images after using image-editing software. It was also intended to show dentists the potential dangers of computerized tools.

MATERIALS AND METHODS

Eight panoramic radiographs and two linear tomographs from the files of the Radiology Clinic at FOP-UNICAMP/BR were scanned into a computer in order to allow manipulation and analysis.

Those images were exported to an I-Omega zip drive* (100 MB storage device) in TIFF-8 BIT format and submitted to an image-editing software.** Nine out of 10 images in the study were modified, with the number of alterations ranging from 1 to 3 in each radiograph, totalling 15 manipulations, all concerned

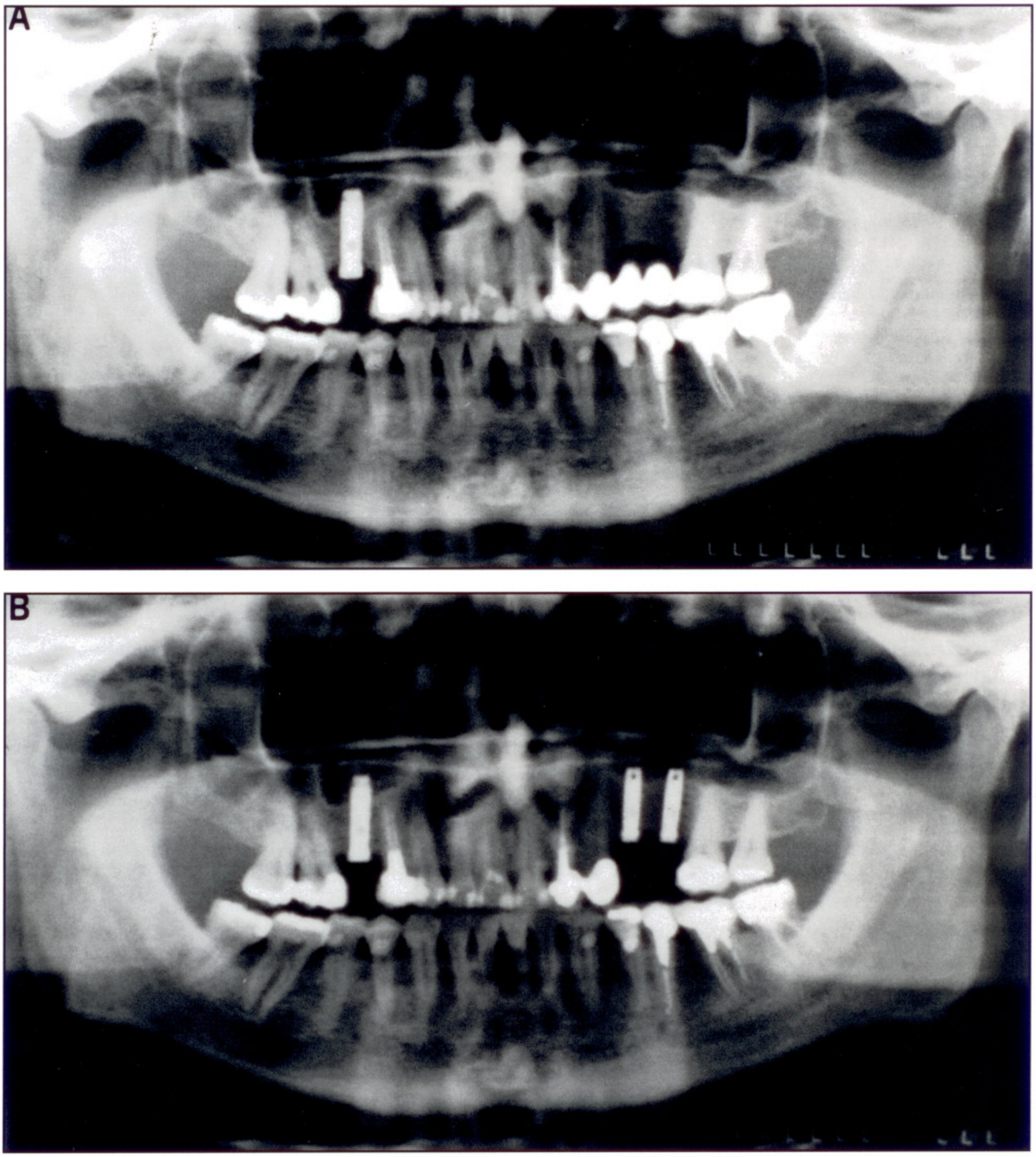

Fig.1: Original (A) and manipulated (B) images, showing the removal of a bridge in the left side of maxilla and replacement with two implants.

* *Hewlett Packard Scanjet 4c/t, Vancouver, WA, USA.*

** *Corel Photo Paint 8, Corel Corporation, Ontario, Canada.*

with implants. Dental implants were added, removed or displaced, bone levels were reduced or increased and prostheses or dental elements were eliminated to favour the placement of implants. All alterations were carried out by radiologists (Figs. 1 and 2).

Seventy dentists in different specialities, such as implantology, surgery, periodontology, radiology, prosthodontics and forensic dentistry were invited to identify the alterations in the images. The radiographs were analyzed on a computer monitor S-VGA, flat-screen, 17 inches, screen configuration

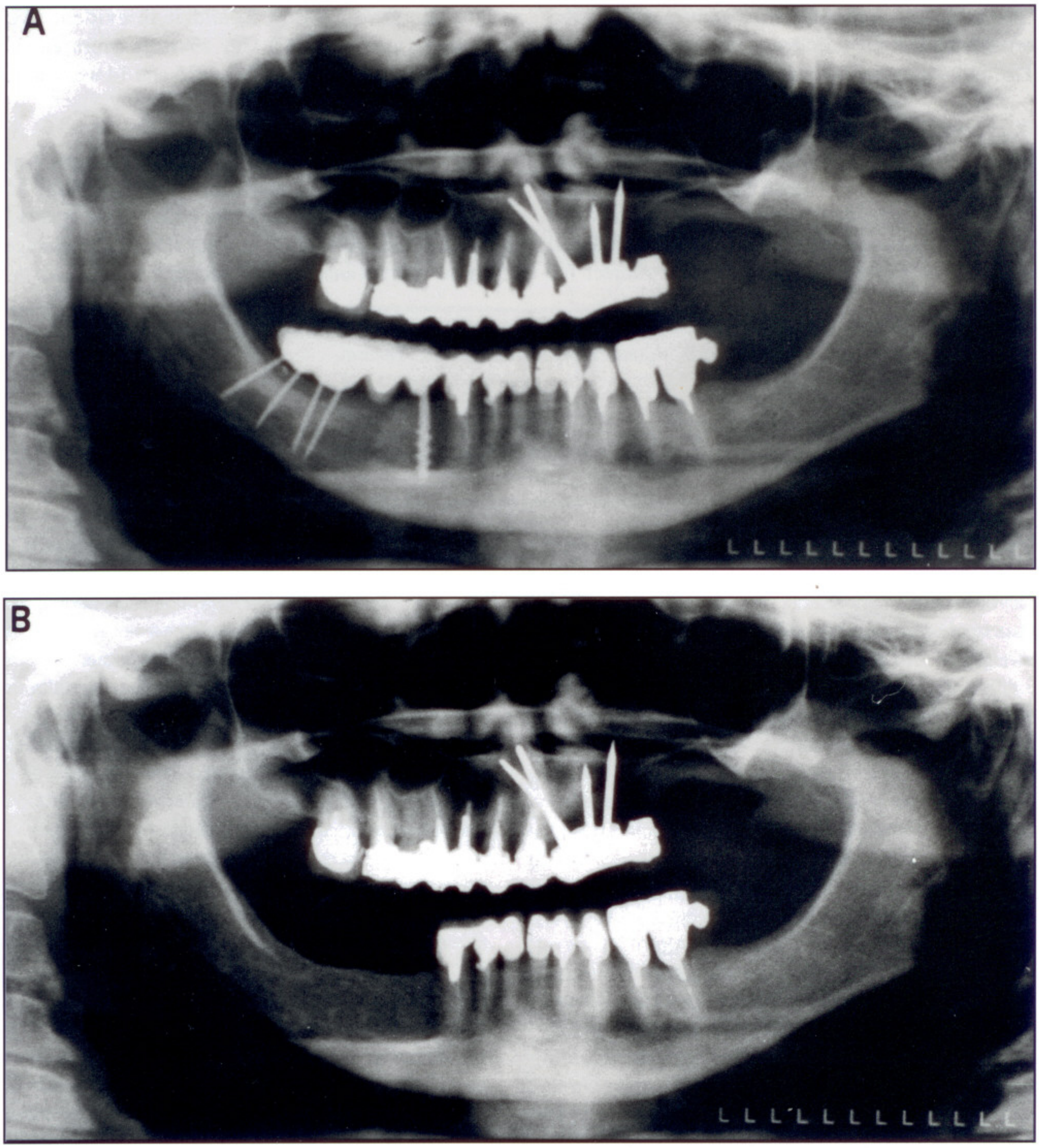

Fig.2: *Original (A) and manipulated (B) images, showing the removal of implants in the right side of mandible.*

of 1024 x 768 resolution pixels and using a Power Point 97† software. Two files were created: one containing the altered images, and another containing the original radiographs in the same sequence as in the first file. Each image was given an identification number (1 to 10), and they were analyzed individually because each slide in the file corresponded to a single radiograph that was exhibited on a black background. Using the "zoom" was permitted, as well as the "brightness and contrast" tool, for any examiner who considered that they needed to enhance the images. The lighting in the analysis room was dimmed.

Each observer received a questionnaire to record any identified alterations for each radiograph. After answering it both the original and the altered images were exhibited side by side so as to show the observers the manipulations that had been introduced and provide some information on the subject for them.

After the observations were concluded, an analysis of both correct true positive and false-positive (presumed, but non-existent manipulations) answers for each examiner was performed.

RESULTS

The radiographs and manipulations carried out are shown in Table 1. The manipulations that were more easily identified and also the ones that were missed are shown in Table 2, and it is evident that manipulations 15, 12 and 13 were more easily detected while manipulations 3, 5 and 14 were more difficult to detect.

The average percentage of correct answers was 12.5%, so it can be concluded that among the 15 manipulations performed and, added to the analysis of the radiograph which was not altered, the average of the correct answers per examiner was 2.0.

† Microsoft Corporation, California, USA

Table 1: *Description of the man ipulations carried out, and their identification and radiograph numbers*

Radiographs number	Region	Manipulation number	Description
1	Maxilla	1	Change of bridge in two crowns
		2	Placement of implant in the area
2	Mandible	3	Implant removed
3	Mandible	4	Implant removed
4	Maxilla	5	Removal of two pontics
		6	Placement of implant A
		7	Placement of implant B
5	Mandible	8	Molar removed
		9	Placement of two implants
6	Maxilla	10	Implant removed
7	Mandible.	11	Implant removed
8	Maxilla	12	Bone level increase in the whole maxilla
	Mandible	13	Bone level reduction in the whole mandible
9	Tomograph	14	Bone level reduction
		15	Placement of a screw to implant
10	Tomograph	non-M	Without alteration

non-M : non-manipulated - radiograph without manipulation.

Table 2: *Numbers and average of examiners' correct answers in decreasing order, according to manipulation.*

Manipulation	CA	%
15	47	67,1
12	15	21,4
13	12	17,1
2	11	15,7
9	9	12,8
10	8	11,4
6	7	10
non-M	6	8,5
4	6	8,5
7	5	7,1
11	5	7,1
1	4	5,7
8	3	4,2
3	1	1,4
5	1	1,4
14	1	1,4

non-M : radiograph without manipulation.
CA : correct answers.

The number of false positives for each examiner was calculated and an average of 12.3 observations for each observer noted. That was done in order to verify the number of presumed but non-existent manipulations which means the rate of false positives in relation to correct answers was at a level of 6:1.

DISCUSSION

The use of computers in dentistry is routine for countless professionals who enjoy their benefits. It is common for them to exchange simultaneous information, such as sending radiographs of patients, by Internet. The same is true regarding insurance companies, when authorizations for treatment are requested, and this useful and practical service is used.

The computer monitor has been used to display radiographic images directly which is appropriate for digital radiography, and furthermore provides good conditions for analysis.

The results of this study show that professional observers, in agreement with the studies of other authors,[4-8] fail to identify alterations such as removed, added or displaced implants and reduced or increased bone levels in radiographs, proving that negligence and malpractice can be disguised in radiographic images which may compromise the legal reliability of this technology. This matter would not be of such importance if all dentists were honest, but unfortunately there will always be those who unscrupulously seek personal interests, not only in dentistry, but also in other professional areas.

The wide range of correct answer rates was no doubt owing to some manipulations being easily identifiable while some were not. Considering that the alterations were performed by dental radiologists, not by computer scientists, it was concluded that the present study shows that alterations can be performed to simulate all levels of difficulty, and it is likely that the more skilled in image editing software the professional who performs the alterations is the higher the difficulty to identify them can be.

Previous studies[4-8] have warned that the radiographic equipment industry should be aware of the seriousness of this situation, and that image protection mechanisms should be developed to eliminate the problem of digital radiography image manipulation, also safeguarding professionals and insurance companies. This problem has not been solved yet however a possible solution would be to print the digital images at the moment they were acquired as it happens to the tomographs and magnetic resonance images.

In conclusion, the results of this study have shown that professionals have difficulty in identifying altered radiographs, the seriousness of which demands that dentists be warned of the dangers of the use and abuse of this technology.

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WEIGHING EVIDENCE: QUANTITATIVE MEASURES OF THE IMPORTANCE OF BITEMARK EVIDENCE

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ABSTRACT

Quantitative measures of the importance of evidence such as the "likelihood ratio" have become increasingly popular in the courtroom. These measures have been used by expert witnesses formally to describe their certainty about a piece of evidence. These measures are commonly interpreted as the amount by which the evidence should revise the opinion of guilt, and thereby summarize the importance of a particular piece of evidence. Unlike DNA evidence, quantitative measures have not been widely used by forensic dentists to describe their certainty when testifying about bitemark evidence. There is, however, no inherent reason why they should not be used to evaluate bitemarks. The purpose of this paper is to describe the likelihood ratio as it might be applied to bitemark evidence. We use a simple bitemark example to define the likelihood ratio, its application, and interpretation. In particular we describe how the jury interprets the likelihood ratio from a Bayesian perspective when evaluating the impact of the evidence on the odds that the accused is guilty. We describe how the dentist would calculate the likelihood ratio based on frequentist interpretations. We also illustrate some of the limitations of the likelihood ratio, and show how those limitations apply to bitemark evidence. We conclude that the quality of bitemark evidence cannot be adequately summarized by the likelihood ratio, and argue that its application in this setting may be more misleading than helpful. **(J Forensic Odontostomatol 2002;20:31-7)**

Keywords: bitemark, Bayesian, likelihood ratio

INTRODUCTION

The thrust of modern bitemark analysis has generally been to resolve mechanistic questions about reproduction, recording and comparison procedures to be followed.[1] Of secondary importance have been questions about the uniqueness of the dentition and about how bitemark evidence is to be presented in the courtroom. Progress in resolving questions about the individuality of tooth shape, size and position[2-6] has been cautious, perhaps because investigators have been loathe to consider dental development from a population perspective. As a consequence, a comprehensive characterization of dental individuality comparable to that of DNA data has not emerged.

The presumption of dental uniqueness is the *raison d'etre* for the admissibility of bitemark evidence.[7,8] Yet if one accepts that no two bites by the same biter will be identical in all ways, and that the principle of individuality implies that no two bitemarks are identical, the question becomes with what confidence can we distinguish between two people's bites on the same surface, and can this confidence be meaningfully quantified?

Unlike DNA evidence, bitemark analysis does not have a quantitative base; thus, it is crucial for the forensic dentist to understand how to relate an inherently qualitative assessment to the quantitative measures used in other fields. Because it is the duty of the expert witness to inform the jury, the goal is to give an appropriate interpretation of certainty of that expert opinion rather than develop a technological black box that produces a number which substitutes for that appropriate interpretation.

Quantitative measures of the importance of a piece of evidence are based on the idea that the perception of guilt can be described using probability. In a criminal trial the jury is instructed to evaluate the evidence, and in that process must assume innocence unless guilt is established "beyond a reasonable doubt." This basic judicial premise implies that the degree of certainty must be a central consideration, and that a guilty decision should only be reached when the probability of innocence is sufficiently small. Jury deliberations can be viewed as the process of determining the probability of guilt, and a "reasonable doubt" could be phrased in terms of this probability. Although it is debatable whether or not formal quantification of uncertainty is helpful to juries, its use during trials is increasing - especially its application to evidence offered by expert witnesses. As a consequence it is important for expert witnesses to develop an understanding and intuition for the measures of uncertainty as applied in the courtroom.

The primary objective of this paper is to describe the application, calculation and interpretation of quantitative measures of the importance and reliability of evidence in forensic dentistry. Since the seminal work of Lindley[10] and Evett[11] there has been a growing interest in the "Bayesian approach" to the quantification and evaluation of expert forensic testimony.[9,12,13] Recent papers by Malokoff,[14] Goodman[15] and others are further evidence for a renewed interest in the Bayesian approach. The principles behind these measures are somewhat abstract, and as a result there is an impression that forensic dental evidence may have become overshadowed by sophisticated and mathematically complex techniques which are not easily understood.[16,17] In fact these measures are all directed at expressing the probability of guilt, and in particular, how that probability changes with new evidence. In what follows, we review these measures and the fundamental ideas from which they derive in order to describe their appropriate interpretation and application to the evaluation of human bitemark evidence.

Quantitative Evaluation of Evidence

A new piece of evidence in a trial revises the certainty or probability of guilt. The amount by which the probability is revised depends on the importance and the quality of the evidence. The jury relies on the expert witness to provide this information so that the evidence has an appropriate impact on the verdict. In this section we describe a formal framework for the interpretation and evaluation of evidence in a trial using a numeric rating know as the "likelihood ratio." We first describe the likelihood ratio as a quantity used to interpret the evidence from the perspective of the jury and then describe the same quantity as a measure used by the expert witness to evaluate the reliability of the evidence. We note that likelihood ratios are sometimes considered synonymous with "Bayesian reasoning" in the courtroom. In the following discussion we describe what this means, and contrast this interpretation with the "frequentist" interpretation used by the expert witness to derive the likelihood ratio.

The jury and the Bayesian interpretation

Conceptually, at the beginning of the trial (in the absence of any evidence and under the presumption of innocence) the probability of guilt should be very small. Initially the probability should be approximately $1/N$ where N is the largest possible number of potential perpetrators (e.g., N is the number of people in the city where the crime occurred). This could be interpreted as the probability that the accused individual has ended up on trial simply because the police randomly selected one individual from this population. It is equivalent to expressing this probability using the "odds." The use of odds originates in wagering where it is the amount of money required for a fair bet. Odds can be calculated from the probability: if the probability of guilt is p, then the odds of guilt are $p/(1-p)$. In a finite sample where p is the proportion of people with a particular trait, then the odds of the trait is the ratio between the number of people with the trait and the number of people without the trait. In our courtroom application, if the initial probability of guilt is $1/N$, then the odds of guilt are:

$$\frac{\frac{1}{N}}{1 - \frac{1}{N}} = \frac{1}{N - 1} \qquad \text{eq 1}$$

The evidence in the trial is used to either increase or decrease the initial probability (or odds) so that a guilty or not-guilty verdict can be returned. One way to interpret the impact of a piece of evidence on the trial, and hence its importance, is to measure how much it revises the probability of guilt. The likelihood ratio (*LR*) is the commonly used measure of the impact of a piece of evidence on the perception of guilt. It is defined as the ratio between the odds of guilt after the evidence is considered to the odds of guilt prior to its introduction:

$$LR = \frac{\textit{odds of guilt given the evidence}}{\textit{odds of guilt prior to evidence}}$$

If the likelihood ratio for a piece of evidence is less than 1.0, then that evidence has decreased the odds of guilt. If it is greater than 1.0, then the odds of guilt are larger than they were without the evidence.

To illustrate, we consider a hypothetical example involving the trial of a man for an assault at a party. Suppose that during the trial it has been clearly established that the assailant was male and attended the party along with 49 other males. Suppose that there are no witnesses, so the guilt or innocence of the defendant will be decided on circumstantial evidence. Furthermore, suppose that the victim was bitten by the assailant, and that a forensic dentist has been asked to evaluate the bitemark and bite casts for all male party goers. On the witness stand, the dentist states that the most prominent feature of the bitemark is the mesiodistal incisor width which is at least 9.5mm, and that the bite casts show that 3 of the 50 male party goers (including the accused) have incisor width exceeding 9.5mm. In this example the prior odds that the accused is guilty are 1/49 (which corresponds to a probability of 1/50), and after the bitemark evidence those odds increase to 1/2 (corresponding to a probability of 1/3). The likelihood ratio calculated using the pre- and post-evidence odds is 1/2 ÷ 1/49 = 24.5. From the jury's perspective, the bitemark evidence has resulted in a 24.5-fold increase in the odds of guilt.

A central requirement for the above calculation is the presence of a clearly defined group of 50 suspects - something which may not be available. Consider a second example in which an assault occurred on the streets of a large city, and the only clearly established prior information is that the assailant is male. In this example we can denote the size of the male population by *N*, but it cannot be directly calculated. Once again, suppose that the dentist determines that the assailant has a mesio-distal incisor width of at least 9.5mm, and that the accused satisfies this condition. Suppose further that population studies indicate that mesiodistal incisor width among males follows a Normal distribution with a mean of 8.7mm and a standard deviation of 0.4mm; that is, the assailant's incisors are at least 2 standard deviations above the mean. From the properties of the Normal distribution, only 2.3% of the population is more than 2 standard deviations above the mean. It follows that the incisor width evidence has reduced the size of the population of potential perpetrators from *N* to 0.023 x *N*. In this example the prior odds of guilt are $1/(N - 1)$ and the revised odds are $1/(0.023\,N - 1)$, so the likelihood ratio (after simplification as in equation 1) is:

$$LR = \frac{1/(rN - 1)}{1/(N - 1} = \frac{1 - \frac{1}{N}}{r - \frac{1}{N}}$$

where *r* is the prevalence of an evidential characteristic in the *N* possible perpetrators. In the above example, $r = 0.023$ and if *N* is large, $LR \approx 1/0.023 = 43.5$. The incisor evidence has produced a 43.5-fold increase in the odds of guilt.

Note that the likelihood ratio requires knowledge of *r* and *N*. In the first example both could be determined by actual measurements taken on all possible perpetrators, which would clearly be impossible in most situations. In the second example it is sufficient to know that *N* is large as long as there is secondary information about the distribution of the bitemark in the relevant population. The second approach is commonly used when there is a natural estimate of the prevalence of an evidential trait. A good example is with DNA testing where the probability of a match in a randomly selected individual can be determined from the number of independent alleles examined. As discussed below, an incorrect likelihood ratio could be obtained if the large population approach were applied to a small group of potential perpetrators or *vice versa*.

The likelihood ratio as defined and interpreted above is a Bayesian quantity because it measures the probability of truth (i.e., guilt) given the data (i.e., evidence). A Bayesian interpretation contrasts with a frequentist interpretation which is based on measuring the probability of the data (evidence) given truth (innocence or guilt). The relative merits of Bayesian and frequentist approaches to statistical analysis is currently the subject of debate. Advocates of frequentist approaches prefer methods that are not affected by an arbitrary prior distribution (a technical necessity for the Bayesian approach), whereas advocates of Bayesian methods prefer the interpretability of a Bayesian analysis. In fact the Bayesian/frequentist argument does not really apply to the interpretation of courtroom evidence. The likelihood ratio has a meaningful frequentist interpretation in addition to its Bayesian interpretation. We now show that a frequentist interpretation is more useful to the expert witness than the Bayesian interpretation used by the jury.

The expert witness and the frequentist evaluation

The expert witness must provide the jury with some indication of the certainty or uncertainty in his/her conclusions about the evidence. When the determination is subjective (as is the case with much of forensic dentistry), then the certainty must be conveyed verbally. When quantitative determinations are possible, then the likelihood ratio provides a more precise measure of certainty. To calculate a likelihood ratio by quantifying the odds of guilt as described above would be inappropriate for an expert witness. The jury must assess guilt; the expert witness must evaluate a particular piece of evidence.

The likelihood ratio can be re-expressed using elementary probability relationships so that the expert witness can report the same likelihood ratio without quantifying the pre- and post-evidence odds of guilt:

$$LR = \frac{\textit{odds of guilt given the evidence}}{\textit{odds of guilt prior to evidence}}$$

$$= \frac{\textit{probability of evidence given guilty}}{\textit{probability of evidence given not guilty}}$$

The first interpretation of the likelihood ratio is the Bayesian measure described above. The second interpretation is a frequentist measure because it describes the probability of the evidence under different assumptions about guilt .

Once again, consider the first example of the assault at the party. Suppose that the dentist has finished testimony and the lawyer for the defence asks for the likelihood ratio as a measure of the importance of the evidence. During evaluation of the bite casts and bitemark the dentist needed to ask two questions: (1) how likely are various bite characteristics in the assailant (the person who made the bitemark - not necessarily the accused), and (2) how likely are those characteristics in the non-guilty population? The dentist must assess the bitemark for one or more distinctive characteristics; i.e., those characteristics which are both readily apparent in the bitemark and uncommon in the non-guilty population. Assigning probabilities to these assessments leads to the alternative form for the likelihood ratio. In the party assault example the dentist would have examined the bitemark and decided that the assailant's incisor width could be measured with certainty, and that wide incisors are relatively rare in the non-guilty population. Expressed as probability, the dentist would be certain that the assailant had an incisor width of at least 9.5mm (i.e., the probability of width $\geq$ 9.5mm in the guilty person is 1.0), and from the casts would measure that 3 of the 50 potential suspects had wide incisors (which implies that 2 of 49 non-guilty individuals had wide incisors). According to the alternative version of the likelihood ratio:

$$LR = \frac{\textit{probability of evidence given guilty}}{\textit{probability of evidence given not guilty}}$$

$$= \frac{1/1}{2/49} = 24.5$$

which is the same as the value derived above by quantifying the odds of guilt.

If, as in the second example, the assault occurred in a large city, it would only be known that the number of potential assailants is very large. Once again, the dentist would select a characteristic which was both readily apparent in the bitemark and rare in the non-guilty population. As in the party example, the incisor width would be a good characteristic if width is readily measured in the bitemark and if the measurement was so extreme as to make it unusual in the general population. If, as above, there are N individuals in the population of potential assailants (1 guilty and N-1 not guilty), and the proportion with incisors larger than 9.5mm is r, then the probability of the wide incisors in the non-guilty portion of the population is $(rN\text{-}1)/(N\text{-}1)$, and the likelihood ratio is:

$$LR = \frac{1}{(rN - 1)/(N - 1)} = \frac{1 - \frac{1}{N}}{r - \frac{1}{N}}$$

Once again, the likelihood ratio is approximately $1/r$ when N is large, and if $r = 0.023$, then $LR = 43.5$ as obtained above when quantifying the odds of guilt.

The frequentist interpretation of the likelihood ratio reflects the difference in definition. In the party assault, the dentist would report that the probability that the assailant has wide incisors is 24.5 times the probability of large incisors in the non-guilty population. The jury would interpret this as the amount by which the pre-evidence odds of guilt have increased. Similarly, in the city assault the dentist reports that the probability of wide incisors in the guilty individuals is 43.5 times the probability of wide incisors in a non-guilty individual; the jury interprets this as change in the pre-evidence odds of guilt.

In the previous section we motivated the likelihood ratio as the jury's *interpretation* of how the evidence changes their perception of guilt. The forensic dentist focuses on the *evaluation* of the evidence, and therefore focuses on its quality. In this role the dentist is interested in unusual characteristics that identify a distinct bitemark which serves to narrow the list of possible suspects. By definition unusual characteristics are rare, and rare characteristics will make high quality bitemark evidence. Thus, the probability of a bite characteristic in the general population is a natural measure for evaluation of the certainty of the evidence. In this regard we suggest that the jury views the likelihood ratio from the Bayesian perspective, and the expert witness views it as a frequentist evaluation.

One issue which is readily apparent in the frequentist interpretation, which is less apparent in the Bayesian interpretation is the role of certainty in characterising a bitemark trait. We assumed in the incisor width example that the dentist was certain that the assailant's incisor width was at least 9.5mm. This assumption was explicit in the frequentist interpretation where the numerator was the probability that the incisor width in the assailant exceeded 9.5mm. If the bitemark evidence was poor, then the dentist may not be certain of this characteristic, and the probability could be chosen to be less than 1.0. In contrast, uncertainty in the characterisation of the bitemark is not as explicit in the Bayesian interpretation where it would alter the odds of guilt given the bitemark characteristic. Once again, the frequentist interpretation is more natural for the dentist who must incorporate uncertainty in the bitemark trait into their assessment.

Limitations of Quantitative Measures

The simple examples given above treat the likelihood ratio as if it is a fixed property that is directly determined by the quality of the evidence. In fact, the likelihood ratio depends both on the size of the population of possible perpetrators (N) and on the prevalence of the evidential trait (r) in that population. It follows that the likelihood ratio will change according to what information is already known at the time the evidence is presented. For example, if N decreases during the course of the trial (as we might expect) then the likelihood ratio will tend to increase as long as r stays constant. For many types of evidence the prevalence of the evidential characteristic, r, is different in different reference populations; thus for example, if we know that the assailant had large feet, then it would not be so unlikely that they would also have large teeth in which case r will be larger and the LR smaller.

We return to the second example to illustrate the interplay between different pieces of evidence and their effect on the likelihood ratio. Suppose that in the large city assault, the gender of the assailant was not clear, so that the initial population included both females and males. Females have smaller teeth, and suppose the probability that incisor width exceeds 9.5mm in a population of females is 0.0062. If the population is equally split between males and females, then the overall probability that the incisor width exceeds 9.5mm is the average of the male and female probabilities, $(0.023 + 0.0062)/2 = 0.0146$. Following the same calculations given earlier, the likelihood ratio when the population of possible assailants includes both males and females is approximately $1/0.0146 = 68.5$, as compared to $1/0.023 = 43.5$ if the assailant is known to be male. Thus, the likelihood ratio may change as the population of possible perpetrators is refined. This can happen both at the initiation of the trial, and if the population is revised by other evidence offered as part of the trial. The likelihood ratio will not change if the particular piece of evidence is completely independent of any other evidence; for example, if the prevalence of large teeth is the same in both males and females, then the likelihood ratio for the incisor width evidence would be the same regardless of whether it followed or preceded any gender evidence.

In many trials the list of potential perpetrators is actually quite small, and as in the party assault example, the evidence is used to select the actual perpetrator from a short list. In this setting it would be inappropriate to use the large population methods described in the second example. For example, suppose that a DNA analyst reports a one in 1,000,000 chance of a match with a randomly selected individual from a large population. If there are only 10 possible perpetrators, then the likelihood ratio cannot be approximately 1,000,000 as it would be in the larger population. If all 10 suspects have DNA profiles and the defendant is the only match, then the likelihood ratio is infinite ($= 1/0 \div 1/9$). If however the DNA matches 3 of the 10 suspects (something which might happen if suspects are related) then the likelihood ratio is 3.0 ($= 1/3 \div 1/9$). In fact bitemark evidence may be most useful in these small-population situations where it is possible to match the mark to a small number of bite casts.

One of the theoretically appealing aspects of the likelihood ratio is that the overall likelihood ratio for large blocks of evidence (or for all evidence) can be calculated by taking the product of all likelihood ratios from the individual pieces of evidence. Unfortunately, this theoretical possibility is impossible in practice. Practical problems arise because some evidence is not amenable to quantification; thus, even with quantifiable evidence, the likelihood ratio will depend on earlier evidence for which quantification may be impossible. Similarly, even if likelihood ratios can be calculated for all previous evidence, it may not be possible to define explicitly the size of the population of potential perpetrators, which as described above can have important effects on the likelihood ratio. Finally, even if a reasonable likelihood ratio can be calculated for every piece of evidence in a trial, it is questionable as to whether or not the quantitative measure would lead to better decisions. One attempt to calculate an overall likelihood ratio in a trial resulted in a reversal of a verdict on the basis that the jury had been misdirected.[18]

DISCUSSION

Interpretation of bitemark evidence is not a quantitative process. Although some characteristics can be directly measured (e.g., tooth dimensions, intercanine distances), the ability to discern measurable characteristics depends very much on the circumstances surrounding the bite; bitemarks are not usually made to facilitate later evaluation. Furthermore, unlike DNA testing, there is no theoretical basis for determining the population prevalence of bitemark characteristics, so even if measurements can be made their distribution (prevalence) in the reference population is probably unknown.

We conclude that bitemark evidence is inherently qualitative, and the use of quantitative measures to describe the importance of bitemark evidence would be misleading. Such quantitative measures must derive from quantitative justification, and basing a likelihood ratio on professional opinion or experience is likely to give a misleading impression of the importance of the evidence and a false sense of objectivity to a subjective determination. This point has recently been emphasised by Taroni et al.,[19] who noted that frequentist probabilities were objective and Bayesian probabilities were subjective. That is, frequentists rely upon long-run repetitions of an observational event under defined and constant conditions. In contrast, Bayesian or subjective probabilities refer to the level of belief that an expert may hold, based on his or her experience, knowledge and information, about a single event whose falsity or truth is unknown.

Although further studies might determine the population prevalence for common bitemark characteristics, calculation of likelihood ratios for bitemark evidence will always be complicated by the variable nature of the circumstances surrounding the bite. This is not to say that bitemark evidence is useless in a courtroom. In fact bitemark evidence may be excellent for selecting the perpetrator from a small group of suspects (as illustrated in the party assault example). However even in these situations the jury may be better informed by a careful explanation of the bite characteristics than a formal calculation of a likelihood ratio.

It is essential that expert witnesses have some understanding of quantitative measures of the importance of evidence. Their use is common, and their apparent objectivity is appealing to judges and lawyers. In some circumstances measures such as the likelihood ratio greatly facilitate the interpretation of a piece of evidence, however inappropriate use serves only to confuse matters. When it comes to bitemark evidence, we recommend that the forensic dentist understand the likelihood ratio, and be able to offer an explanation (based on issues described above) of why it may not apply to the case at hand.

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A CRITIQUE OF AGE ESTIMATION USING ATTRITION AS THE SOLE INDICATOR

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ABSTRACT

The age determination of skeletal remains has been carried out using anthropological examination of the remaining bones and dentition. The aging of the dentition is based on attrition which, if physiological will correlate with age. Occasionally the only material available is a single tooth or a few teeth, or in the case of a living person, teeth *in situ*. In certain cases microscopic examination of the teeth may not be possible and the age estimation is then often determined by the degree of attrition associated with the tooth. In more recent times the causes of attrition have involved other factors such as bruxism, diet, environment and medication. The weaknesses and limitations of age estimation by examination of dental attrition as the sole indicator of age are highlighted. **(J Forensic Odontostomatol 2002;20:38-42)**

Key Words: Age estimation, attrition, bruxism, weaknesses

INTRODUCTION

This paper reviews the literature covering tooth wear as an indicator of age of an adult skeleton and shows why in the absence of microscopic examination of the sectioned tooth, attrition should not be relied upon as a sole indicator of age.

REVIEW

The aging of subadults can usually be determined very accurately because of a large number of age-dependent morphological features and dental development in particular is one of the most accurate indicators of age. All but the third molars are completely calcified by 16 yrs followed at age 25 yrs by the third molars.[1]

At the end of skeletal growth the number of these age-dependent morphological features declines. The teeth are formed, most epiphyses are united and longitudinal bone growth is complete. However, in a recent study on the development of the medial clavicular epiphysis and its fusion with the clavicular shaft it was recorded that complete union first occurred at 22 yrs with all subjects showing complete union by 27 yrs.[2]

In the aging of an adult skeleton a number of criteria need to be considered and assessed together and these include macroscopic changes such as metamorphosis of the pubic symphysis, suture closure in the skull, and age-related changes such as degeneration of the spine, skull and joints, resorption of cancellous bone and dental attrition. Microscopic changes occur in the long-bone cortex and the teeth.[3]

In aging cases, occasionally all that remains are some teeth, or just one tooth. This is because teeth are less affected than other parts of the body by exogenous factors such as heat, fire, bodily trauma or scavenging animals. The first anthropological method used to age an adult skeleton by the teeth was attrition which is the physiological wearing away of the tooth as a result of tooth to tooth contact, as in mastication or bruxism. This is in contrast to abrasion which is the pathological wearing away of the tooth through some abnormal mechanical process which can be caused by food or non-food items such as pipes, pins and tooth brushes. Attrition is assessed by examining the occlusal and incisal tooth surfaces and there have been a number of attempts to quantify the wear of teeth and then to allocate an age to the skeleton.[4-10]

This method has been based on anthropological/ archaeological theory which relies on the fact that attrition occurs at a specific or linear rate throughout an adult's lifetime.[11] In archaeological specimens however an adult's longevity was considerably less than contemporary man and the attrition was the result of a coarse diet. Miles[5] suggested that the Breedon Anglo-Saxon population in his study lived to approximately 31 years compared with 62 years in 1937 and 71 years in 1963 for the British population.

Most of the methods used to determine and quantify attrition contain a degree of subjectivity and often the results were difficult to reproduce without some training in the technique used.[12-15]

In 1950 Gustafson[4] developed a method for aging adult teeth by looking at the six variables: degree of attrition, changes in the periodontium, the amount of secondary dentine, cementum apposition, the degree of root resorption and the degree of root transparency. The teeth were scored for each variable then combined in a formula, and an age determined for the teeth and the skeleton. Some of these variables required microscopic examination after sectioning and histological preparation of the tooth. Despite criticism[12,16] the Gustafson technique has remained the definitive method of determining age-at-death of the adult skeleton, but it has over the years been modified.[8-10,17]

More recently much research has focused on techniques using the transparency of the root dentine[18-20] and the application of image analysis to a number of microscopic changes,[21,22] which can be regarded as objective methods.

Despite the existence and relative accuracy of aging the skeleton by observing microscopic changes in the teeth, for a number of reasons these techniques are not always employed. Rogers[23] has suggested that while the techniques are quite accurate, they have limited forensic use mainly because the teeth have to be removed and destroyed. The procedures are exacting and time consuming, and are often beyond the immediate capability of many agencies that need the information. Kvaal[24] agrees with Rogers pointing out that a destructive approach may not be acceptable for ethical, religious, cultural or scientific reasons and that furthermore in a living person these techniques require extraction which may not be acceptable. Some methods are difficult to perform and the necessary laboratory equipment (ranging from a simple microscope to a scanning electron microscope connected to suitable computer software) and necessary expertise may not be available.[19,20] Metzger[14] points out that if these techniques are not often used, it is difficult to develop operator skill. Finally, many of these techniques are costly to carry out.

One of the non-microscopic techniques for the aging of a contemporary skeleton using the dentition at death is attrition. It is a relatively simple procedure, requiring minimal equipment, is inexpensive and less invasive. It does however require some expertise[12-15] but is still subjective and not very accurate as demonstrated in the amount of correlation variation between studies[25] resulting in very broad age ranges. Attrition in contemporary man is furthermore subject to a number of variables which can affect the estimation of age.

Different scoring methods result in different correlations between age and attrition. Teeth wear at different rates, so different correlations also exist between them, as Solheim[26] found in second premolars which had the highest correlation and canines and maxillary central incisors which had the weakest. Lopez-Nicolas[19] reported that the correlation between age and attrition improved with progression from anterior to the posterior teeth. The number of teeth examined from an individual affects the correlation[4,25,27] and age estimation from a single tooth is very weak. There is general agreement that accuracy of the technique declines as age increases, resulting in a broad age range, a view supported by Hongwei and Jingtao[28] using contemporary skeletons and a mathematical model, who found that accuracy decreased with age and they believe that aging by attrition had limited dento-legal applications. This was especially true in resolving the chronological age of living people who have inadequate identification papers.[29]

When attrition is used by anthropologists to age non-contemporary skeletons, the main cause of tooth wear is grit and a coarse diet and when linked to age[30] is regarded as normal physiological wear. In 1970 Lavelle stated that masticatory function, type of food, timing and sequence of tooth eruption, tooth form, position of the tooth, thickness of the enamel, hardness of the enamel and predisposition to enamel hypoplasia all played roles in attrition. This list is almost identical to that drawn up by Murphy[6] and fits in with factors outlined by McKee [11] while other studies have found that rates of attrition vary within a population.[10,19,27,30]

In contemporary man the causes of some attrition have changed in the last 50 years and attrition is no longer considered to be related to age[15] but its cause is multifactorial. Including the factors listed by Lavelle,[31] other causes are the number of teeth, the quality and quantity of tooth contacts, the location of the tooth in the jaw, the relationship with the opposing jaw, the mobility and periodontal status, cuspal height, the bite force, the amount of bruxing, quality and quantity of saliva, chemical and mechanical factors related to diet, gender, age and gastrointestinal disturbances.[15]

It is well established that bruxing is a complex disorder caused by a number of factors which Pavone[32] summarized as psychological, emotional, dental, systemic, occupational and idiopathic. Xhong[33] attributed attrition to bruxing, nervous tension and occlusal prematurities, causing tooth wear to progress faster in bruxers than non-bruxers. She found that wear facets occurred three times more in bruxers than non-bruxers and concluded that physiological wearing of the teeth no longer had a linear relationship with an increase in age.

In a 20-year study in Queensland, Xhong[33] also found that a relationship existed between bruxing and erosion, attributing the erosion to a high intake of acidic, flavoured drinks associated with the hot climate. The erosion was a result of acid demineralization which softened the teeth making them more susceptible to the forces of bruxism.

A study of mentally challenged people concluded that "the degree of dental wear in this group of individuals is significantly different from that of an urban population in the same geographical area".[34] The increased wear was attributed to unconscious clenching or bruxing habits, developed by these individuals as a kind of self-stimulation, regurgitation and as a result of the side effects of psychopharmacological therapy. The side effects claimed for some of these drugs does include bruxing.

In a study on Indian vegetarians[35] it was found that although the attrition was not great, when compared to non-vegetarians the vegetarians had greater tooth wear which they attributed to consumption of harder, more acidic foods, a finding supported by Dahl and Olio.[15]

A study comparing wear rates of 19 year-old Norwegians living in Norway and a similar age group of Indians living in Saudi Arabia found that the Indians had a higher wear rate which was attributable to the environment which would have included ambient fine sand particles where in the Norwegians no obvious environmental factor could be identified.[36]

The general population has a desire to retain the natural dentition rather than losing teeth which often results in endodontic treatments in order to retain them. Ingle[37] suggests that the restoration of choice for a large endodontically treated tooth is full coverage crowning, which can also apply to cases of severe attrition. This can result in masking the nature of the wear and rendering age estimation by attrition useless particularly when using image analysis and linear measurements.[38] A similar finding was reported by Kvaal[24] when using dental radiographs to estimate age and Lavelle[31] who found that even simple amalgam fillings interfered with attrition scoring for an individual. A degree of attrition also occurs when modern restorative materials oppose the natural dentition[18,39] with different types of materials affecting the pattern and the degree of wear.

CONCLUSION

Age estimation by examination of dental attrition as a sole indicator should be avoided if possible. Where applicable it should be used in conjunction with other techniques, both dental and anthropological. There are circumstances where minimal skeletal remains preclude anthropological aging, or where more sophisticated dental aging techniques are not available. In these instances the following procedure needs to be employed. Two operators utilizing the same scoring method need to examine as many teeth as possible from the same individual which should include an assessment of the occlusion if possible.[14] The weaknesses and limitations of this method also need to be kept in mind. These include the relative inaccuracy of the technique, different attrition rates of different teeth within and between different populations of people, coupled with the increasing occurrence of multifactorial bruxing in contemporary man. All of these factors contributing to attrition make it difficult to determine if the attrition is a result of physiological wear or bruxing. There are also only a few population standards for estimation of age on the basis of dental attrition.

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THE CURRENT STATUS OF LIP PRINTS AND THEIR USE FOR IDENTIFICATION

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ABSTRACT

The use of lip prints for human identification was first suggested in 1950 and research was carried out on lip prints in the 1960s and early 1970s, resuming in the last few years. Although lip print identification has been utilized in court in isolated cases more research needs to be conducted in this field with regard to confirmation of uniqueness, and the collection and interpretation of evidence. Lip print identification needs to be acceptable in court as scientifically evidence based. **J Forensic Odontostomatol 2002;20:43-6)**

Key Words: Lip prints, identification, research, court

INTRODUCTION

The idea of using lip prints for identification was first suggested by Le Moyne Snyder in 1950 in his book *Homicide Investigation*.[1] A review of the literature indicates that from the 1960s through until 1975 some research was conducted on the use of lip prints as a source of human identification.[2,3,4] This article looks at the history of lip prints, where and how this evidence has been used in the courts and where it stands as a source of forensic evidence today.

REVIEW

History of lip prints as a means of identification

In the mid 1960s Santos[2] in Brazil and Suzuki[3] in Japan were investigating the use of lip prints as a source of human identification. Santos suggested that the wrinkles and grooves found on the lips could be divided into simple and compound types, which could be further divided into eight other types.

Suzuki in a study investigating lipstick, found that none of his participants had the same lip groove pattern. Following this discovery Suzuki carried out more investigations, collecting lip prints and using methods similar to finger print recording, from a number of individuals, both male and female over a range of ages, and including a group of twins. Any lips which showed any inflammation, injury, cicatrization, or deformity were excluded; these abnormalities are however personal identification markers in themselves. He divided the lips into four quadrants and devised his own classification of six different types of grooves. As the pattern of grooves on the lip varies, one lip can be allocated several types and each quadrant was allocated two different groove types. He demonstrated that no two lip prints manifested the same pattern, that lip prints of twins although very similar were not identical and that lip print characteristics may be inherited from either parent.

In 1974 Tsuchihashi,[4] who had earlier worked with Suzuki, carried out another study. His study included a greater number of participants as well as family groups and his results were similar to Suzuki's. By comparing the lip prints of the twins with their parents he found that they closely resembled one parent which adds strength to the theory of the heredity of lip prints. This study was a longitudinal one recording monthly lip prints over a three-year period of some participants and finding that their lip prints did not change. He also found that following trauma to a lip it resumed its groove pattern after healing.

Following this research in the 1970s, identification using lip prints appears to have been taught to police officers in the United States of America. James Cron, who was a lieutenant with the Dallas Sheriff's department taught lip print identification in the 1980s and 1990s in Texas[5] and the FBI Latent Fingerprint Section in Washington D.C. currently conducts Lip Print Workshops.[6] A school in the United States of America includes some activities on lip print identification in its science program.[7]

Current research

A review of the literature comes up with very little on research into lip prints from the mid-1970s until 2000 where some research has been carried out by a group in Spain.[8] Lipstick smears are often left as trace evidence and can link a suspect to a crime scene. In recent years however the cosmetic industry has been developing lipsticks which do not leave a visible smear or mark in contact and have been called persistent lipsticks. This Spanish group has looked into the latent lip prints left behind by these new lipsticks and their possible use as forensic evidence. After applying the persistent lipsticks, lip prints were made on a variety of materials and were developed after intervals ranging from two hours to thirty hours following impression, using a variety of techniques similar to those used in lifting fingerprints. They found that different developers performed better than others and that no lip prints could be developed on fabric using any developer. They suggested that with the introduction of new smearless or markless lipsticks the possibility of latent lip prints should be considered.[8]

The results of this study with regard to latent lip prints is interesting. Fingerprints are developed by a number of methods which rely on the fact that sweat and body oils which have been transferred from the body to an object react with a number of reagents to become visible. Fingerprint powders adhere to sweat and body oils, iodine when heated reacts with sweat, ninhydrin reacts with the amino acids in sweat, heated cyanoacrylate (Super Glue) reveals latent prints, and sweat will fluoresce when illuminated by a laser. The vermillion borders of the lips have minor salivary glands and sebaceous glands, the latter being principally present around the edges of the lip associated with hair follicles, with sweat glands in between, and secreting oils. Moving from the lip to the alveolar mucosa, crossing the transitional zone, there are occasional sebaceous glands and the lip is also subject to drying, requiring moisturising by the tongue. With these secretions and continual moisturising therefore it would be logical to think that latent lip prints would be available at all crime scenes if they were looked for. Items which may have lip prints, such as glass, could be tested for latent prints using some of the above methods.

Discussions with members of the Finger Print Division of the Western Australia Police Force have confirmed this. Williams[9] also stated that lip prints could be recorded without the use of lipstick or other recording medium provided a suitable (non-porous) surface had been used which was then developed for prints.

Recording lip prints

Lip prints can be recorded in a number of ways. On a non-porous flat surface such as a mirror they can be photographed, enlarged and overlay tracings made of the grooves. They can be photographed directly with no medium and tracings made but this requires correct lighting.[9] Rouge can be applied to the lips and then the lips are photographed[4] while Williams[9] suggests that after lipstick is applied to the lip multiple records or readings should be taken until all the transfer medium is exhausted. This technique would be the same as collecting finger prints by pressing inked fingers on to special paper, which was used early on, and the images then observed through a magnifying glass and traced onto cellophane.[4] Provided the lip print is left on a suitable medium it can be developed using a number of different powders[8] or cyanoacrylate and photographed. The powders used are the same as for fingerprint development and the latent lip prints must be dry.

Problems with lip prints

The lip crease pattern is on the vermillion border of the lip, which is quite mobile and lip prints may vary in appearance according to the pressure, direction and method used in making the print. If lipstick is used as a recording medium the amount applied may also affect the print.[4] To overcome this, several sets of prints should be taken until all the recording medium has been exhausted and lip prints are then evaluated on a pattern comparison between a known and unknown lip print. The print is traced manually which presents problems with reproduction and introduces some subjectivity to the comparison.

Unfortunately, over the years, lip prints have been lumped together with other identification methods that have not gained a large following. These include examining fingernail striations, palm and elbow creases and eye retina patterns. Individualisation of animals by examining stripes on tigers and zebras has also been attempted.[10]

Lip prints in court

Since 1923 admissibility of evidence in court in the United States of America has been based on the Frye test which assumed a general acceptance of the presented evidence by the relevant scientific community. In recent decades the Frye test has been rejected in favour of the Federal Rules of Evidence, which provides for all evidence to be admissible and general acceptance of the evidence as not necessary.

The actual use of lip prints in court is rare and its acceptance debatable. Professor Jay Siegel (Professor of Forensic Science and Associate Director of the School of Criminal Justice, Michigan State University)[11] considers lip print evidence to be admissible in court but the FBI has used lip prints as a means of positive identification only once.[9]

A current controversial case is that of *People v. Davis*, No. 2-97-0725 in an Appellate Court in Illinois, USA. The first court trial has accepted the evidence of two state police experts (a fingerprint examiner and a document examiner) that lip print identification is generally accepted within the forensic science community as a means of positive identification because it appears in the literature, that the identification methodology is an accepted form of scientific comparison, that there is no dissent within the forensic science community with regard to this technique and that the FBI has used it. This case has been appealed.

Each of the above statements has been and can be questioned. Although lip print identification may appear in the field literature there is very little science or research to support Suzuki's theory that lip prints are individual, or to support a methodology, for the collection and comparison of lip prints, which has become accepted within the forensic community. Professor Andre Moessens (Professor of Law at University of Missouri-Kansas City School of Law and author of *Scientific Evidence in Civil and Criminal Cases*)[12] believes that with this lack of sound scientific basis, this technique would fail to meet any scientific standards of reliability.

In Australia the criteria for admitting or rejecting novel scientific evidence has not been defined.[13] However on the basis of several cases involving forensic dentistry [Carroll v The Queen (1985) 19A Crim R 410, Lewis v The Queen (1987) 29A Crim R 267, Chamberlain v The Queen (No 2 (1984) 153 CLR 521 at 558] it appears that the acceptance of evidence related to forensic odontology relies on general acceptance of the evidence.

In New Zealand there is no clear line in relation to expert evidence but it appears that they are heading in the same direction as the United States of America.[14] In Canada in 1994 the Frye test was cited as being the relevant legal standard for the admissibility of novel scientific evidence.[15]

CONCLUSION

Despite the fact that identification of an individual by lip prints appears to be accepted in some places this procedure for identification requires more study. The uniqueness of lip prints needs to be confirmed and accepted, a standard and uniform procedure needs to be developed for the collection, the development and recording of lip prints and the ensuing comparison that will occur. Until then identification by lip prints will not stand up to rigorous interrogation in court.

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