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CONTENTS

THE DETECTION OF MORPHINE AND CODEINE IN HUMAN TEETH: AN AID IN THE IDENTIFICATION AND STUDY OF HUMAN SKELETAL REMAINS

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ABSTRACT

When studying unidentified putrefied or skeletonised human remains it may be difficult to obtain information on drug habits which may prove important for the construction of a biological profile or lead to hypotheses on the manner of death. The detection of morphine and codeine in teeth from human remains may prove crucial in obtaining such information and thus give forensic odontology and anthropology a further tool for identification. Because teeth can be an important deposit of exogenous substances accumulated both in the pulp and in the calcified tissues, they are an invaluable source of data from a toxicological point of view. The authors therefore tested 3 groups of teeth for morphine and codeine: the first group consisted of artificially aged teeth from individuals known to have died of heroin overdose; the second, of teeth from individuals with no history of drug abuse; the third, of teeth from cases of burnt, putrefied and skeletonised remains found in conditions strongly suggestive of a drug-related death. Results showed that in groups 1 and 3 morphine and codeine could still be identified in the teeth, proving that these tissues may be a reliable source for toxicological information concerning the history of the individual. Further studies are needed to verify whether the substances detected reflect drugs in circulation in an acute phase (and therefore present in blood vessels in the pulp) or whether they represent drugs which have percolated and been stored in dentine and enamel and thus denote a history of drug abuse. Nonetheless this study shows that teeth may be an important source of toxicological information in the forensic scenario.
(J Forensic Odontostomatol 2003;21:1-5)

Keywords: Forensic odontology, identification, forensic toxicology, morphine, codeine, drug abuse

INTRODUCTION

When human skeletal and dental remains are found the two main problems which arise are identification of the person and determination of the cause and manner of death. Lack of preservation of soft tissues not only impairs identification procedures but often makes it very difficult to determine the cause of death in the absence of obvious skeletal trauma.

An average of 20 cases of badly putrefied, burnt or skeletonised human remains are found every year in Milan.[1] In most cases a biological profile (i.e. gender, age, race, pathology, occupational traits, habits, etc.) of the person has to be constructed as there are no indications of the person's identity and, furthermore, in most cases, the cause of death remains undetermined.

Forensic toxicology may be a valuable aid if applied to potentially one of the best preserved tissues, the teeth. In fact the sensitivity and specificity of modern forensic toxicological analyses have given investigators very powerful means for detecting even small quantities of xenobiotic substances.

Although the detection of morphine or other drug-related substances from teeth will certainly not *per se* solve the problem of identification nor provide a certain cause of death, it can give important indications as to particular "habits" or indicate a history of drug abuse. This is a piece of information which is obviously important in reconstructing a person's biological and – to a certain extent – social profile, and is equally important, when no other cause of death is found, in suggesting – but not proving – a drug-related death. In the past ten years the number of heroin addicts dying of overdose has passed 100 cases in the city of Milan alone and many of these individuals die in suspicious circumstances, with virtually no identity.

It is known that teeth are a remarkable "diary" of a person's life history. Not only can lifestyle, occupational and dietary habits (eg. tobacco, alcohol, etc.) leave behind visible traces but many types of drugs taken in life by the person may leave chemical foot prints in the teeth, such as tetracycline,[2] certain alcohols and monocarbonic acids.[3] There is therefore reason to believe that teeth may provide excellent biochemical markers concerning the "drug" history of the person to whom the remains belong, in particular concerning the consumption of opiates.

It is not known how difficult the retrieval of such substances may be from old dental material. Many studies have concentrated on verifying the survival and diagenesis of biomolecules of "non-toxicological" interest from dental tissues and already much is known about survival of DNA,[4] albumin and other important biomolecules [5,6] in the teeth. Diagenetic research however has never been performed on teeth to study the survival of toxic substances of forensic interest (in particular those concerning drug abuse), whereas such studies, aimed at the detection of opiates in particular and other substances of abuse, have been performed on non-calcified tissues such as hair and nails.[7,8,9] It is apparent now that many substances will survive in time within the dental tissues and the chemistry of the inorganic component of teeth may in fact be well capable of retaining parts of molecules which could be informative of that specific person's history. Collins and Westbroek[10] have proved that biomineral will provide some degree of protection of biomolecules from biological or chemical degradation and further, that specific targeting of certain drugs onto hydroxyapatite crystals by small peptide conjugation has been demonstrated.

We therefore performed a pilot study on artificially aged teeth from individuals known to have died of drug overdose and on teeth from real forensic cases in order to verify the detectability of two commonly found substances, morphine (a metabolite of heroin) and codeine, in fresh and aged teeth with a post-mortem interval (PMI) of up to two years.

MATERIALS AND METHODS

The study was performed on three groups of teeth. A first sample of teeth (group 1) consisted of artificially aged positive-control ten lower first molars (each tooth taken from a separate cadaver), ranging in weight from 1.5g to 3.5 g, extracted from well preserved cadavers of individuals who had died of heroin overdose. This was done in order to verify the methods of morphine extraction and detection from teeth on a "known" sample which initially presented optimal preservation of blood and soft tissues. These individuals had all been found with circumstantial evidence of heroin injection (a syringe near the cadaver) and had shown blood levels of morphine greater than 1 μg/ml, and were also positive for codeine. After extraction the teeth were cleaned and washed in distilled water and artificially aged at room temperature, under a hood, in a dry environment. One tooth was then crushed for testing at postmortem intervals (PMIs) of 5 days, 1 month, 6 months, 8 months, 4 teeth at 12 months and 2 teeth at 18 months.

Group 2 consisted of 10 molars, ranging in weight from 1.6 g to 3.5 g, (each tooth taken from a separate cadaver), from individuals with no history of heroin addiction and with no circumstantial evidence for antemortem heroin, morphine or codeine use; these teeth were aged in the same manner and tested at the same PMIs as group 1, as negative controls. For this group blood tests from the cadaver for morphine and codeine resulted negative.

Finally, group 3 was composed of teeth from 4 cases of unidentified human remains. Case 1 was a saponified body of a young adult male who had been in water (river) for approximately one month. Cases 2 and 3 were those of badly burnt and decomposed bodies with an estimated PMI of 15 days. Case 4 was the skeletal remains of a young male with an estimated PMI of 2 years. Cases 2, 3 and 4 had syringes containing heroine found next to them. Analyses on the viscera and remaining body fluids of all individuals except Case 4 (the skeletonised remains) had previously tested positive for both

CASE	TOOTH (wt in g)	MORPHINE (ng/g)	CODEINE (ng/g)
No. 1 saponified cadaver PMI = 1 month	molar (1.7) premolar (1.1) incisor (1.1)	38.83 35.09 76.75	28.00 15.81 8.88
No. 2 burnt cadaver (1) PMI = 15 days	molar (3.6) premolar (1.8)	22.59 28.60	12.46 8.74
No. 3 burnt cadaver (2) PMI = 15 days	molar (2.0) premolar (1.4)	8.24 6.94	5.47 2.99
No. 4 skeleton PMI = 2 yrs	molar (3g)	83.03	16.97

Table 1: *Results of morphine and codeine tests on single teeth from group 3*

Positive controls: all teeth from drug addicts with drug related cause of death , artificially aged up to 18 months tested positive for morphine and codeine.
Negative controls: all teeth from individuals with no history of drug abuse and natual cause of death tested negative for morphine and codeine.

morphine and codeine. For case 1, one molar (1.7g), one incisor (1.1g) and one premolar (1.1g) were examined. In cases 2 and 3 one premolar and one molar for each burnt body were tested (1.8g and 1.4g respectively for the premolars, and 3.6 and 2.0g respectively for the molars). In case 4 one molar (3g) was tested (Table 1). (For group 3 the study was extended to all teeth according to availability).

Teeth were washed and cleaned of all blood and soil residues in distilled water and were gently polished (both crown and root) in order to eliminate any external contaminant. They were then incubated at room temperature in vials containing distilled water, rotated for 24 hrs and pulverised with an IKA ceramic mill* (the mill was cleaned overnight between teeth with "Ausilab" detergent),† after which 1.8g of tooth powder was incubated in 0.25M HCL overnight in an oven at 60°C and hydrolysed for 18 hrs in 2 ml of 0.25 M HCl at 50°C.

Reagents
Morphine hydrochloride, codeine hydrochloride and derivatising agents were obtained from Sigma‡ and the solvents and HCl were obtained from Merck.§

Extraction
Fifty µl of morphine-d_3 (1µg/ml) were added to the acid as an internal standard and purification was performed with n-heptane-isoamylalcohol (98.5:1.5). After mixing and centrifugation the solvent was discarded, the acid converted to alkaline (pH 9) and extracted with 4 ml of chloroform:isopropanol:n-heptane (50:33:17). Test tubes were then shaken for 15 min and centrifuged at 3500 rpm for 10 min, the solvent was separated and evaporated in a rotating evaporator and the residue was derivatised with 100 µl of pentafluoranhydride and 70 µl of pentafluoropropanol at 90°C for 15 min. The derivatising agent was dried with nitrogen and the residue reconstituted in 50 µl of ethylacetate. Codeine and morphine standards were now extracted at concentrations of 5, 10, 25, 50, 100 ng with the same quantity of internal standards (morphine-d_3)

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† *Carlo Erba, gruppo Pharmacia, via Robert Koch, 1.2, Milano, Italy.*
‡ *Sigma, 3050 Spruce St., St. Louis, MO 63103, USA.*
§ *Merck, P.O. Box 100, Whitehouse Station, NJ, 08889, USA.*

GC/MS conditions (Gas Chroma-tography/Mass Spectrometry)
GC/MS analyses (on 2 _l) were performed using a Hewlett Packard gas chromatograph[¶] mod. 6890 equipped with a 7673 HP autosample and MSD 5973 HP.[†] The gas chromatography was carried out with a MS5 (HP),[¶] length 12 m, internal diameter 0.2mm and 0.33 micron film thickness. The injection port temperature was 260°C (pulsed splitless mode) and the carrier gas was helium (8.4 psi head pressure, working at constant flux conditions) 1 ml/min constant flux. The oven temperature was held at 70°C for 2 min following injection and then programmed to progressively increase to 200°C at a rate of 20°C/ min and successive increments of 8 min up to 250°C and a final increase of 40°C per minute up to 280°C. The MSD detector was selected for single ion acquisition and precisely for ions 414, 430 and 577 m/z for morphine, ions 266, 282 and 445 m/z for codeine and ions 417, 433 and 580 m/z for deutered morphine. Temperature of the quadrupole was set at 150°C; source 230°C and 2 μl of each sample, followed by the standards, were then injected into the GC/MS. The identification of morphine and codeine was performed by comparing retention times, by the presence of ions selected and their ratios.

RESULTS

For groups 1 and 2 which had been tested in an initial part of the study aimed only at giving a qualitative assessment, the teeth were simply scored as positive or negative for morphine and codeine. All teeth from group 1 (artificially aged for up to 18 months) tested positive for morphine and codeine while all teeth from group 2 tested negative for these two substances, which confirmed that teeth from cadavers with no history of drug abuse test negative. Teeth from individuals known to have a history of drug abuse and to have died of drug overdose always gave positive results for morphine and codeine.

Results obtained for group 3 are illustrated in Table 1 which shows that morphine and codeine were found in all specimens, even in the case of skeletal remains with a PMI of 2 years.

¶ *Agilent Technologies, 395 Page Mill Rd., P.O. Box 10395, Palo Alto, CA 94303, USA*

DISCUSSION

The scope of this pilot study was to test the detectability of morphine and codeine in human teeth from individuals with different post-mortem intervals and in different conditions of preservation and to prove that in known drug abusers morphine can be detected in their teeth up to 2 years after death.

Until now the detection of substances of forensic toxicological interest had been performed on many types of difficult substrates, for example hair and nails,[7,8,9] but never on teeth in different states of preservation and from individuals with different PMIs. The potential of a method for detecting even small quantities of morphine in old dental tissues is enormous. When nothing but bones and teeth remain, detecting drugs such as morphine or codeine may be a crucial element in building a biological profile. In fact, other signs of drug abuse such as syringes may not be present at the crime scene and the individual may not be suspected of being a drug abuser. The presence of morphine and codeine in teeth may therefore be the only clue to drug abuse, placing the person in the drug abuser category and helping investigating authorities to search for missing persons among specific social groups. Furthermore, it may lead to hypotheses on the cause of death (i.e drug overdose) although a correlation between the presence of morphine in teeth and in the circulation still needs to be investigated.

This study leads to further questions: are the morphine and codeine residues telling us what was in circulation at the time of death or do they represent old deposits accumulated during life? If what we have extracted from the teeth actually derives from the pulp, then is it likely that we have been extracting substances present in the pulp vessels at the time of death? Or might we be detecting substances accumulated during life which have penetrated and been stored in dentine or enamel? Future studies ought therefore to concentrate on separating these two dental sources (pulp and other tissues) in order to verify the route of contamination. This may also help explain why apparently "smaller" teeth sometimes yield larger quantities of morphine. For identification purposes a positive or negative qualitative result may be sufficient to provide information on a person's drug history. If the presence of morphine however is to be used to verify a possible cause of death then information on the amount of morphine present in the vessels in the pulp is necessary and this requires isolation of morphine from the pulp and its quantification.

CONCLUSIONS

This study provides a novel perspective in the analysis of human remains for reconstructing the history of drug abuse of a person. The detection of morphine and codeine in artificially aged human teeth (up to 18 months from death) from individuals known to have a history of drug abuse and known to have died of drug overdose, and with a PMI of up to 2 years, proves that once again teeth are a remarkable source of data on the toxicological history of a person. Although further studies are needed to verify that the substances detected reflect drugs present in the circulation in an acute phase (and therefore in the blood vessels in the pulp) or whether they represent drugs which have percolated and been stored in dentine and enamel and thus denote a history of drug abuse, this study shows that teeth are an important source of information. The detection of morphine in teeth from human remains may give clues concerning a potential drug-related death but it can especially provide a "personal descriptor" crucial to constructing a biological profile which may lead to identification.

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ARE A MINIMUM NUMBER OF CONCORDANT MATCHES NEEDED TO ESTABLISH IDENTITY IN FORENSIC ODONTOLOGY?

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ABSTRACT

Forensic odontology plays an important role in the identification of human remains. While numerous studies[2-6] have proven conclusively the uniqueness of the human dentition, forensic odontologists worldwide remain divided about the need for a minimum number of concordant points to confirm dental identification[4-6, 9-16]. This study reviewed 690 cases from the archives of the Forensic Odontology Unit, The University of Adelaide, to determine the validity of using a minimum number of concordant points to positively identify human remains. It was found that positive identification had been established using a varying number of concordant points. Although the incidence of positive identification was more frequent with a minimum of 12 concordant points, there were numerous cases where 12 or more concordant points failed to achieve a positive identification. Identities were also confirmed in some cases using less than 12 points of correspondence. There appears to be no basis for defining a minimum number of concordant points necessary before a positive identification can be made on dental evidence. Rather, the findings of this study reinforce the view that each case has its own individuality and should be treated as such. **(J Forensic Odontostomatol 2003;21:6-13)**

Key words: Identification categories, concordant points, dental statistics

INTRODUCTION

Identity refers to the characteristics by which a person may be recognised. Dental identity may be broadly defined as the total of all characteristics of the teeth and their associated structures which, while not individually unique, when considered together provide a unique totality.

Identification of the unknown individual is important in the present-day world for legal and humanitarian reasons[1], indeed Haglund and Morton[2] considered identification of an individual to be the most important aspect of forensic odontology. The underlying tenet for dental identification is that combinations of dental characteristics are never the same in any two given individuals and numerous researchers[3-6] have elaborated on the uniqueness of individual human dentitions. This individuality, however, does not ensure that all cases can be positively identified.

Based on the quality and quantity of concordant points available different 'levels' or 'categories' of identification can be assigned to cases that indicate their proximity to a positive identification. For example, McKenna[7] proposed the following categories: (1) positive identification; (2) highly probable identification; (3) consistent with but equivocal; (4) impossible to identify; (5) inconsistent with; and (6) definitive exclusion. Similarly, Silverstein[8] recommended a classification of: (1) positive identification; (2) possible identification; (3) insufficient evidence; and (4) exclusion.

The Forensic Odontology Unit at the University of Adelaide uses the following identification terminology:
Confirms identity: where identity is proven beyond reasonable doubt, including radiographic comparisons.

Strongly supports identity: where there is a high level of concordance between postmortem and ante-mortem information without radiographic support.
Supports identification: where explainable differences exist between the two sets of information.
Does not confirm or exclude identification: involves cases with minimal or insufficient information (either postmortem or ante-mortem).
Excludes identification: contains unexplainable inconsistencies that comprehensively indicate a mismatch.

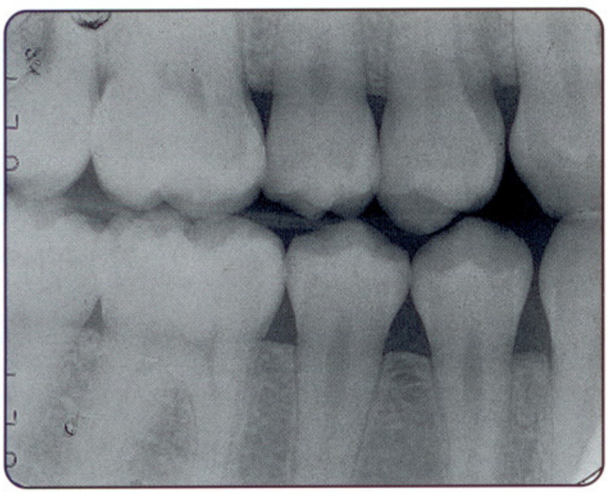
Various researchers have focussed on the number of teeth or features required to establish a positive identification. Following the approach used for fingerprint identification, Keiser-Nielsen[4] proposed that 12 concordant points be the required number for a positive dental identification and other researchers[5,6,9] have agreed that a minimum number of concordant points are needed to establish positive identity.

The tendency to link the probability of identity based on the number of points of correspondence has its limitations. Hill[10] stated that emphasis on numerical indices could be misleading and confusing to legal professionals and lay people. Locard (cited in Taroni *et al* [11]) considered that there was more to the evaluation of identification than the mere counting of characteristics, while a few researchers[9,12] have reported that just one identical radiographic characteristic may be sufficient to establish identity. It is also accepted that the recovery of only a single tooth or jaw fragment may be enough to confirm a positive identification, provided appropriate ante-mortem records are available[13]. Other authors[14-16] have reported positive identifications based on unique and unusual points of concordance but a review of the literature indicates a lack of consensus about the need for a minimum number of concordant points for positive dental identification. This study aimed to determine the need for a minimum number of concordant points for dental identitification, based on 21 years of experience in 690 identification cases at the Forensic Odontology Unit, The University of Adelaide.

MATERIALS AND METHODS

The archives of the Forensic Odontology Unit house a total of 1302 cases, 612 of which involved non-identification cases including bitemark cases (305), age determination (125), missing persons (81), homicides (60) and skeletal remains (41). The remaining 690 cases involved identification of unknown persons, and these were accessed in this study.

All cases that required identification were reviewed with the objective of establishing the number of concordant points used in each instance, thereby



Antemortem

Postmortem

Fig.1: *Radiographs showing teeth with similar morphology (Courtesy: Forensic Odontology Unit archives, University of Adelaide)*

determining the need for a minimum number of concordant points in positive dental identifications.

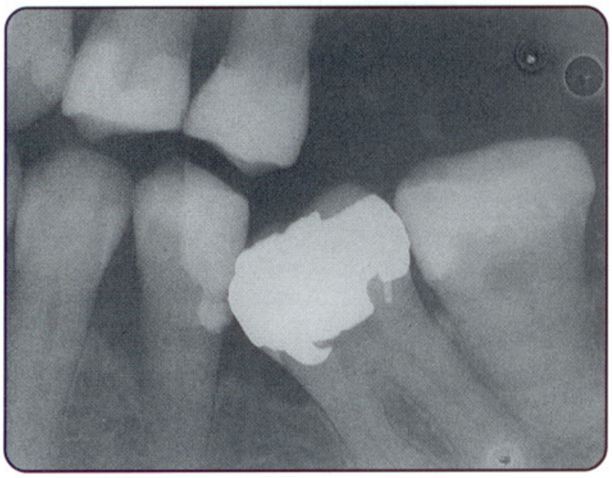
Determination of identity involves matching postmortem data with ante-mortem records. The data may include morphology of teeth, the restorations contained in them, as well as associated anatomical structures and pathological processes. In an attempt to encompass all characteristics used frequently in the dental identification process a broad term "*concordant point*" has been defined. For this study, if a sound tooth were found to be matching in both the postmortem data and ante-mortem records (Fig. 1), this was classified as one *concordant tooth*. If a tooth with a restoration were found to be matching in both sets of data (Fig. 2), the concordance would still be with respect to one tooth. The restoration in this tooth is a *concordant feature* and was not considered separately since it was already a part of the concordant tooth except in instances where there was severe fragmentation or loss of the dental tissues and the restoration had been dislodged and found alone. Similarly, if the postmortem and ante-mortem radiographs revealed a pathological feature such as a cyst, this was considered as a *concordant characteristic*; as was the presence of an amalgam tattoo, extraction socket, trabecular bone pattern, etc.

In summary, features within the domain of a tooth were considered to be a part of the concordant tooth and were not considered separately. Those features beyond the domain of the tooth were automatically acknowledged as concordant characteristics. Concordant teeth and concordant characteristics constituted *concordant points*.

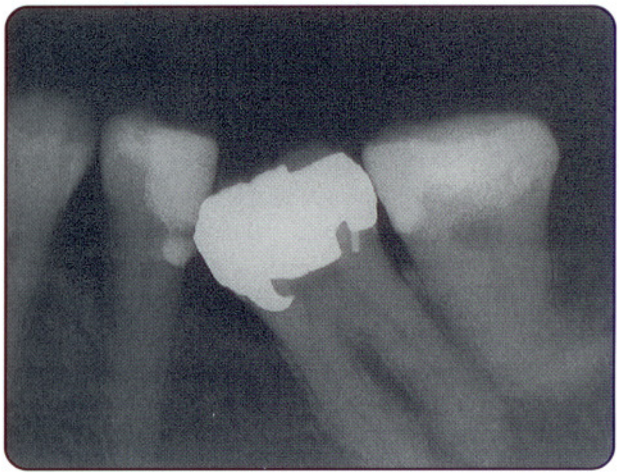
RESULTS

Of the 690 identification cases reviewed, 104 cases were identified visually, by fingerprints or other methods, and hence did not require a dental input. Eighty-three of the 690 cases did not have any available dental records and hence an attempt at identification was not possible. Five-hundred-and-three cases of identification had some form of dental record available of which 245 (48.7%) 'confirmed' identity while 258 did not. These 258 cases were categorised as follows: 40 (7.9%) 'strongly supports' identification; 166 (33.0%) 'supports' identification; 50 (9.9%) 'does not exclude or confirm' identification; and 2 (0.04%) 'exclusion' of identity.

The 245 cases that 'confirmed' identity used concordant points ranging in number from 1 to 33 (Fig. 3). Forty-eight (19.6%) cases used between 1 and 11 concordant points. One-hundred-and-ninety-five (79.6%) cases used 12 or more concordant points of which 35 (14.3%) used between 12 and 16 concordant points, 51 (20.8%) between 17 and 22 points, 56 (22.9%) between 23 and 27 points, and 53 (21.6%) between 28 and 33 points. Radiographic evidence aided 72 of the 245 (29.4%) positively identified cases. Fifty- eight of these used 12 or more



Antemortem



Postmortem

Fig.2: Radiographs showing teeth with identical restoration patterns. The restorations in the teeth are not considered as separate concordant points (Courtesy: Forensic Odontology Unit archives, University of Adelaide)

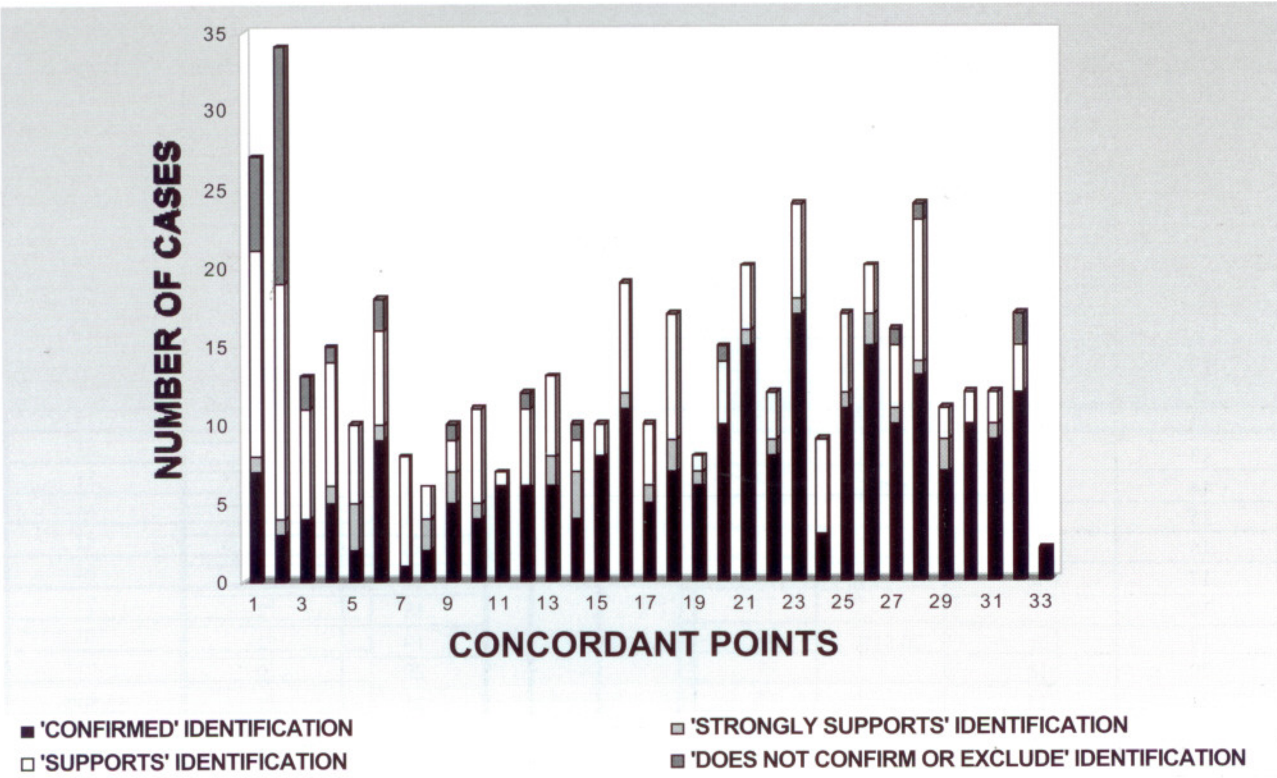


Fig.3: *Frequency of concordant points in 'Confirmed', 'Strongly Supports', 'Supports' and 'Does not Confirm or Exclude' cases of dental identification*

concordant points, emphasising the importance of quality radiographs in positive dental identification. Two cases were positively identified using video-superimposition alone, for which the number of concordant points was not available.

Fig. 3 also shows 40 cases that 'strongly support' dental identification, with concordant points ranging from 1 to 32. Twenty-six (65.0%) of these 40 cases were lacking in complete ante-mortem dental records, while 15 (37.5%) presented either limited postmortem dental remains, nomenclature differences in the comparison process or charting errors in the ante-mortem records. Twenty-one (52.5%) cases used 12 or more concordant points.

One-hundred-and-sixty-six identification cases with dental records contained evidence only to 'support' the identification. Of these, 95 (57.2%) had incomplete ante-mortem records while nomenclature differences and charting errors contributed to 28 (16.9%) cases. Limited post-mortem details of the dental status, severe peri-mortem trauma and incineration of remains contributed to 18 of the 166 (10.8%) cases. In addition, unlabelled dentures featured in 14 (8.4%) of the cases. Eighty-seven of the 166 (52.4%) cases provided 12 or more concordant points, yet failed to establish a positive identification (Fig. 3). There was a high frequency of 2 concordant points in this category due to the presence of 7 cases with unlabelled complete dentures (one denture was taken as one concordant point).

Fifty of the 503 cases with dental records 'neither confirmed nor excluded' identification (Fig. 3). Of these, 21 (42.0%) had incomplete dental records and 11 (22.0%) had limited post-mortem data or peri-mortem trauma. Thirteen cases of unlabelled dentures ensured that the frequency of 2 concordant points was the highest (Fig. 3). Identity was 'excluded' in 2 cases due to obvious discrepancies that could not be explained in any way.

Concordant Points	Frequency of Occurrence	Percentage of Concordant Points		Strong X-ray Evidence
1	7			
2	3			
3	4			
4	5			
5	2			
6	9	19.59%		14 Cases
7	1			
8	2			
9	5			
10	4			
11	6			
12	6			
13	6			
14	4	14.29%		
15	8			
16	11			
17	5			
18	7			
19	6	20.81%		
20	10			
21	15			
22	8		79.59%	58 Cases
23	17			
24	3			
25	11	22.86%		
26	15			
27	10			
28	13			
29	7			
30	10	21.63%		
31	9			
32	12			
33	2			

***Table 1:** 'Confirmed' Dental Identification*

Concordant Points	Frequency of Occurrence	≥ 12 Concordant Points
1	1	
2	1	
3	0	
4	1	
5	3	
6	1	
7	0	
8	2	
9	2	
10	1	
11	0	
12	0	
13	2	
14	3	
15	0	
16	1	
17	1	
18	2	
19	1	
20	0	
21	1	52.50%
22	1	
23	1	
24	0	
25	1	
26	2	
27	1	
28	1	
29	2	
30	0	
31	1	
32	0	

***Table 2:** 'Strongly Supports' Dental Identification*

DISCUSSION

Of 245 cases in which identity was 'confirmed', between 1 and 11 concordant points were used for 48 cases. This means that 19.6% of all 'confirmed' cases were based on fewer than 12 concordant points which was suggested as 'a minimum' for positive dental identification by Keiser-Nielsen[4].

Fifty-two percent of cases that 'strongly supported' identification, 52.4% of cases that 'supported' and 14% that 'did not confirm or exclude' identification were based on 12 or more concordant points, making a total of 44.6% of cases that could not be positively identified despite having 12 or more concordant points. Hence, the presence of a minimum of 12 concordant points does not always establish a positive dental identification.

Keiser-Nielsen[4] suggested the use of 'a minimum' of 12 concordant points for positive dental identification but the basis for selecting 12 concordant points as a threshold was not explained beyond "joining our fingerprint colleagues". The rationale for this minimum to be 'safe' was not explained, nor has the rationale for equating one 'extra-ordinary' feature to two 'ordinary' features, or how this is statistically possible. The premise of Keiser-Nielsen's argument that 'an ignorance of the frequency of occurrence of dental characteristics would undermine the value of a single unique feature' cannot be justified, because the uniqueness of the human dentition is beyond doubt.

Concordant Points	Frequency of Occurrence	≥ 12 Concordant Points
1	13	
2	15	
3	7	
4	8	
5	5	
6	6	
7	7	
8	2	
9	2	
10	6	
11	1	
12	5	52.41%
13	5	
14	2	
15	2	
16	7	
17	4	
18	8	
19	1	
20	4	
21	4	
22	3	
23	6	
24	6	
25	5	
26	3	
27	4	
28	9	
29	2	
30	2	
31	2	
32	3	

***Table 3:** 'Supports' Dental Identification*

Concordant Points	Frequency of Occurrence	≥ 12 Concordant Points
1	6	
2	15	
3	2	
4	1	
5	0	
6	2	
7	0	
8	0	
9	1	
10	0	
11	0	
12	1	14%
13	0	
14	1	
15	0	
16	0	
17	0	
18	0	
19	0	
20	1	
21	0	
22	0	
23	0	
24	0	
25	0	
26	0	
27	1	
28	1	
29	0	
30	0	
31	0	
32	2	

***Table 4:** 'Does not Exclude or Confirm' Dental Identity*

Twenty-six of 40 (65%) cases that 'strongly supported' dental identification, 95 of 166 (57.23%) that 'supported' and 21 of 50 (42%) cases that 'did not confirm or exclude' identity lacked complete ante-mortem records. These incomplete dental records were a result of failure on the part of the dentist to record the existing dental status of the patient upon initial appointment or because the patient had changed dentists more recently, with the later treatment records being unavailable. There were two cases for which strong radiographic evidence relating to trabecular bone pattern and root morphology respectively were available, but the absence of restorations perhaps prompted the odontologist to rule out a positive identification.

Nomenclature differences and charting errors contributed to 28 of 166 (16.9%) cases that 'supported' and 13 of 40 (32.5%) cases that 'strongly supported' dental identity. In all, incomplete dental records undermined a positive dental identification in 142 of 503 (28.2%) identification cases with dental records, while nomenclature differences and charting errors contributed to 41 of 503 (8.2%) cases. This, once again underlines the importance of complete and accurate ante-mortem dental records to enable a positive dental identification.

Limited post-mortem details of the dental status, severe peri-mortem trauma and incineration of remains contributed to 18 of 166 (10.8%) cases that 'supported' identification, 2 of 40 (5.0%) of 'strongly supported' and 11 of 50 (22.0%) cases that 'did not confirm or exclude' identity. In all, 31 of 258 (12.0%) cases that 'strongly supported', 'supported', 'did not exclude or confirm' and 'excluded' identity were influenced by peri-mortem effects on the dental tissues which reinforces the importance of complete and intact recovery of teeth to give a better chance of positive identification.

Unlabelled dentures contributed to a total of 27 of 258 (10.5%) cases that could not be positively identified and the need for legislation to make denture labelling mandatory should not be forgotten.

The present study has shown that a positive identification can be obtained from as little as one concordant point but that concordant points used to establish identity in fact ranged from 1 to 33. A total of 195 cases were positively identified using 12 or more concordant points. This, however, does not imply that the likelihood of a positive identification is increased with a minimum of 12 concordant points since it has also been found in the current study that 12 or more concordant points were recorded in 44.6% of cases that could not be positively identified.

One of the most frequent reasons for non-confirmation of identity was incomplete or unavailable ante-mortem dental records, a common occurrence which once again emphasises the dependence on them for dental identification. In addition, the use of different nomenclatures provided a constant reminder of the need for uniformity in charting teeth, and for the odontologist to be familiar with a number of recording systems. Positive dental identification depends upon the quality of information available in addition to the quantity, including availability of radiographs, presence of multiple restorations and/or unique features in the dentition.

CONCLUSION

The legal and societal needs for positive identification place the forensic odontologist in a position of great responsibility. The need for a minimum number of concordant points in a positive dental identification is not supported by this study, which reinforces the importance of treating each case on its individual merits. A single concordant point may be sufficient to confirm identity, while a full mouth series of radiographs may not prove positive identification if details are lacking. The forensic odontologist must be aware of the circumstances under which a single extraordinary dental feature may be used for identification and its uniqueness should be gauged and utilised accordingly. In accidents involving a limited number of people whose names are known, the points used for identification could be limited to a unique tooth/feature/characteristic for distinguishing the victims, however, in instances of mass casualties, a unique feature may not be extraordinary enough to identify an individual. Ultimately, the discretion of identification lies with the forensic odontologist who must be aware of the repercussions of a mis-identification and be satisfied that the conclusions can be justified in a court of law, the ultimate peer review[17].

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FORENSIC ASPECTS OF GUIDELINES

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ABSTRACT

In lawsuits concerning medical or dental litigation a question regularly arising is whether the treatment was in accordance with best practice. In recent times doctors and dentists have increasingly been confronted with so called recommendations, guidelines, directives etc., which should help them to reach the required standard. They are theoretically legally binding in different degrees, for example, guidelines are not binding where directives are. Such differences however can hardly be expected to be reflected in everyday legal routine and no matter whether the doctor has deviated from a recommendation, a guideline or a directive, it will complicate the chances of success in a lawsuit. It is therefore important to be aware of these potential judicial implications when formulating guidelines and other instructions or recommendations in order to avoid paving the way for legal pitfalls, which at the very least would lead to over-defensive medical/dental practice. Nevertheless, guidelines can be of value as long as they are not rigid regulations but rather readily usable, comprehensible information on the current state of practice. They could then also have a positive influence on judicially commissioned expert evidence. **(J Forensic Odontostomatol 2003;21:14-6)**

Keywords: Best practice, guidelines, legal obligation, expert evidence

The legalisation of all spheres of life has long since included and permeated through the health sciences. Medical and dental activities are subject to the judicial system in the same way as any other profession, and litigations on treatments have become a routine part of court procedures. One regularly recurring issue is whether the treatment was in accordance with the latest level of medical/dental knowledge, or whether it was flawed.[1] In terms of the legal definition set out in § 276 of the German Civil Code, a culpable treatment error is committed by "whoever fails to take the due care necessary in any transaction". It is thus a matter of observing due care and attention essential to transactions, and this is measured against the respective benchmark.

The Federal Court of Justice has defined the term "improper treatment" as follows: "whether the doctor is guilty of improper treatment that has led to impairment of the patient's health is decided solely on the basis of whether the doctor, by applying the medical knowledge and experience to be expected of him, has made reasonable decisions on the diagnostic and therapeutic measures in the case and has carried out these measures with due care".[2]

The duty to take care is based on the therapeutic standard that a prudent, conscientious practitioner would have offered the patient. If a practitioner's individual skills fall short of this standard, they cannot take recourse to a modification of the standard for their own purposes.[3] For this reason, the practitioner currently undergoing undergraduate or postgraduate training cannot plead inadequate experience, nor the elderly practitioner inability to adapt to new treatment methods, or the very busy practitioner insufficient time for continuing education.

In the event of liability, it is ultimately the courts that decide on whether the necessary duty of care has been infringed or reasonable medical standards observed, but they do not define this standard which is in fact set by medical science. In the event of litigation, it is the task of the officially appointed medical expert to measure the facts against this standard. We are all aware that substantial differences of opinion concerning the appropriate diagnostic and therapeutic measures are not infrequent among members of the medical/dental professions. However, the ruling in a legal dispute must not be allowed to depend on which school the court-appointed expert adheres to or the treatment method they themselves prefer. What matters is rather whether the doctor giving the treatment is (still) within the boundaries of what is diagnostically and therapeutically acceptable in the interests of the patient according to research and experience.[4]

It is at this point that defined scopes of action, recommendations, guidelines, directives etc. assume judicial relevance. Although they lack a judicial status and do not dictate either the kind or the scope of the treatment given to the patient they represent the legal standard for what is permitted and appropriate in the doctor's action and – a very important point – they define the minimum standard in so far as the patient's safety is concerned.[5]

Frequent attempts are made to differentiate between recommendations, guidelines and directives according to the degree of their legal validity and it seems quite feasible to establish the differences in theory, but they may be so subtle that they can hardly be expected to be useful in everyday legal routine.

The patient who believes that they have been improperly treated, or their attorney, will probe into the expanding raft of recommendations, directives and guidelines until something or other that might have been infringed has been found. The doctor is then at least compelled to explain why, even if it was only a recommendation, they failed to adhere to it, deviated from it, or even acted contrary to it. If they fail to make this explanation plausible, it will normally prejudice the chances of success in a lawsuit. The patient's attorney will go one step further and claim that the non-observance of medical recommendations, directives or guidelines constitutes gross negligence. The aim, as those with forensic experience know only too well, is to reverse the burden of proof. If this line of reasoning can be asserted, the patient no longer needs to prove that the doctor's conduct was the cause of the alleged damage. The fact is rather that the doctor must prove that the damage was not the consequence of an action but would have occurred irrespective of it – in most cases a hopeless situation. It is vital always to be aware of these potential judicial implications when formulating directives and other instructions or recommendations, to avoid paving the way inadvertently or negligently for legal pitfalls. The fact is unfortunately that it already exists: briefs are being submitted to the courts without being based on sound and structured judicial foundations but presented rather as a series of directives downloaded from the Internet and combined into brief form. The doctor facing the charge cannot simply challenge such statements but is compelled to come to grips with them from a professional standpoint and to explain why either the recommendations, guidelines or directives in question are not relevant or why, if they are relevant, they deviated from them.

Another potential risk is inherent in the fact that it might occur to third-party insurers seeking to minimize payouts to provide in their policy conditions for an invalidation of the insurance coverage in the event of a directive being infringed – a consideration that the insurers are most likely to have imposed upon themselves at the outset of the debate on directives.

Against this background it is easy to understand the frequently expressed concern that doctors/dentists will initially adhere slavishly to the directives for fear of prosecution and that medical/dental practice might degenerate into mere "checklist medical science"[6] and thus into "codified mediocrity". That would be contrary to the purpose of directives in medical/dental terms: enhancing treatment quality. However, the risks pointed out here should not discourage the pursuance of this objective. Evidence-based health science should be presented to the practitioner not so much as a prescribed course of action or regulation but rather as readily usable, comprehensible information on the current best practice. As such, it can also discredit a widespread prejudice that action-oriented directives or standards contradict therapeutic freedom. Therapeutic freedom does not, in fact, imply therapeutic arbitrariness but it can be present and can demand to be protected only within current best practice, which is *per se* a measure of our duty to take due care. Therapeutic latitude however also implies therapeutic responsibility and this is certainly easier to sustain within a defined and tested environment.

The existence of transparency is also of further significance where legal evaluation, and in particular the re-evaluation of our work under European law urgently recommends an operating definition of the current state of medico-science. The European liability regulations in the service sector have now been suspended for the health professions but are most unlikely to have been abandoned completely. Accordingly, in somewhat simplified terms, a patient would no longer have to prove to the doctor that the fault on the part of the latter had been the underlying cause of the damage to the patient. The fact is rather that the damage would be suspected from the very outset to have been caused by the doctor, and the doctor would have to disprove this suspicion, as it were, by proving that everything had been done correctly.

If this situation, as applicable to European law, were to be revived for the health professions too, then the doctor/dentist would be dependent on recommendations, directives, scopes of action etc. They would all encompass current best-practice in medico-science and the doctor would have a chance of proving in the documented counter-argument that the treatment had been subject to due care.

By the same token, defining the highest standards of medico-science can exert a positive influence on the judicially commissioned expert evidence. It contributes towards making good medical/dental practice transparent, thus placing the expert evidence on an objective basis, and towards taking some of the tension out of medical liability legislation, which is still prone to severe mistrust.

In summary therefore, there are many positive aspects to be derived in medicolegal terms from directives as an expression of the current scientific knowledge. In terms of liability legislation there is indeed a risk of abuse, but directives always need to be reconsidered and reformulated if the outcome is not to be over-defensive medical/dental practice.

If the optimistic assumption is made that all those involved observe and treat the spirit and the limits of directives realistically, then the advantages should clearly outweigh the potential risks.

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COPPER VAPOUR LASER ID LABELLING ON METAL DENTURES AND RESTORATIONS

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ABSTRACT

Denture marking is accepted as a means of identifying dentures and persons in geriatric institutions, or post-mortem during war, crimes, civil unrest, natural and mass disasters. Labelling on the acrylic resin component of the denture can easily be damaged or destroyed by fire but on cobalt-chromium components it would be more resistant. A copper vapour laser (CVL) can be used to label the cobalt-chromium components of dentures and metal restorations easily, and legibly, and miniaturised for the incorporation of more personal particulars necessary for the identification of the deceased person. The CVL beam is focussed by its optics and delivered to the material surface by the two-axis scanner mounted with mirrors. A personal computer controls the movement of the scanner and the firing of the CVL. The high peak power of the pulsed CVL is focussed to very high energy density producing plasma ablation of the alloy surface. Very fine markings of a few microns width can be produced enabling the storage of detailed information of the deceased person on a metal surface for the purpose of rapid identification. **(J Forensic Odontostomatol 2003;21:17-22)**

Keywords: ID-markings, forensic odontology, copper-vapour laser, metal dentures and restorations

INTRODUCTION

Denture marking is necessary for a number of social and forensic reasons. These include the identification of dentures during construction in the laboratory, the identification of persons in geriatric institutions and hospitals who are unconscious or suffering from amnesia, senility or Alzheimer's disease and the post-mortem identification of victims of crime, accidents, mass disaster, civil disorder, war, terrorism and the like. The important role of dental evidence in the positive identification of deceased victims has become widely recognised.[1-4] The massive public awareness after mass disasters requires prompt identification of the victims which depends heavily upon ante-mortem dental records supplied by dentists.[5,6] The records may include dental charts, radiographs, models and even photographs of patients, the last three items providing evidence for visual comparison but dental charts are essential for matching the surviving restorations and prostheses as described on the post-mortem charting sheets. Delays in identification of deceased bodies can cause social problems such as the delay and arrangement of the proper burial rites and procedures. It can also cause inconvenience and hardship because of legal problems and may delay insurance claims and inheritance of property.

When sheltered from fire, complete dentures are an important potential source of information for identification, particularly if they are legibly marked with numbers or names which can be traced to a record of the wearer. Such data can even survive a fire if scribed, embossed or engraved on a high melting point metal foil cured into the denture base.

Denture wearing patterns vary according to the location and age of the wearers. According to the World Health Organisation,[7] in Europe the proportion of 65-74 year-olds who are edentulous varied from

12.8% to 69.6%, with the mean number of teeth ranging from 15.1 to 3.8. These high numbers suggest that denture marking should be mandatory, a procedure that has been recommended by the FDI since 1972, and is now law in seven states in the USA.[8] In Sweden, the Swedish Board of Health and Welfare recommends that all patients should be offered the opportunity to have their dentures marked, but the patients can choose to refuse. The marking of all new dentures is recommended by the Australian Dental Association. The use of a patient's national identification number together with letters indicating the country of origin instead of inserting the patient's name was first described by Thomas.[9]

Various methods of denture marking have been described[8-21] and they can be classified under one of the following categories:

1. writing on the surface of the denture,
2. engraving on the surface of the denture or the surface of the cast (before processing the denture) and
3. inclusion of paper, plastic or metal labels or ceramic chips into the acrylic components of the denture during[14] or after processing the denture.

However, markings on non-fireproof labels in the denture acrylic resin may be damaged or destroyed if the denture is burnt in a fire. Fireproof metal foils embossed by a typewriter are available commercially and where applicable the metal component of a removable partial denture could be engraved, but this is difficult.[16] The engraving would normally be done by hand so it may not be legible and the characters would not be sufficiently small to incorporate enough personal particulars. Various micro-labelling techniques have also been developed[19-21] where more information can be included. Fonts of conventional size (10 to 12) only allow the country code and personal identification numbers to be accommodated but fonts of size 6 or smaller allow the person's name, gender, country of origin and personal identification number to be included. The telephone number of next-of-kin can even be incorporated, allowing more rapid identification and notification.

A particularly attractive option is the use of high power lasers for the micro-labelling of dentures. Lasers are well established in industry, especially in the cutting and welding of metals and their use is also becoming common in biomedical technology with various applications in dental procedures such as the cutting of dental enamel and dentine, soft tissue surgery, periodontics and certain endodontic procedures.

In order to be able to engrave on metallic surfaces, pulse lasers with high peak power operating at high repetition rates are necessary. Some of the lasers that can be used are excimer lasers such as KrF lasers emitting output in the UV wavelengths which are generally too expensive and solid state Nd-YAG lasers which are suitable laser sources but their infrared output wavelength (1.06 mm) is less than ideal due to its lower absorption by metallic surfaces. Its frequency doubling to the yellow-green wavelength (0.53 mm) provides better light absorption properties although it means a lower operating efficiency. On the other hand, recent advances in high power metal vapour laser technology have enabled the engraving and labelling of metal objects not only to be possible, but also miniaturized to a high degree. This report presents a method of labelling cobalt-chromium metal alloys, metal restorations and fire resistant metal foils using a high power copper vapour laser (CVL).

Copper vapour lasers have a high level of efficiency with their output wavelengths of 511 and 578 nm and are normally operated at high pulse repetition frequency of 5 to 20 kHz. Typical output power is in the range of 5 to 20 W with a single pulse energy of more than 1 mJ. With a short pulse length of 15-20 ns, the CVLs offer a useful laser source with high peak power exceeding 50 kW. Using an optical lens, a 1 cm diameter output laser beam can be focussed to a diffraction-limited spot of a few microns in diameter. This will then produce an intense spot of light with power density exceeding tens of gigawatts per cm^2 which leads to the formation of plasma ionization at the surface of the material. The plasma formed produces micro-ablation leading to permanent markings on the surface of a metal. By scanning a pair of mirrors mounted on two galvanometers in two perpendicular axes, and controlled by microcomputers, micro-engraving of information on dentures can readily be made using much the same technology as graphic plotters.

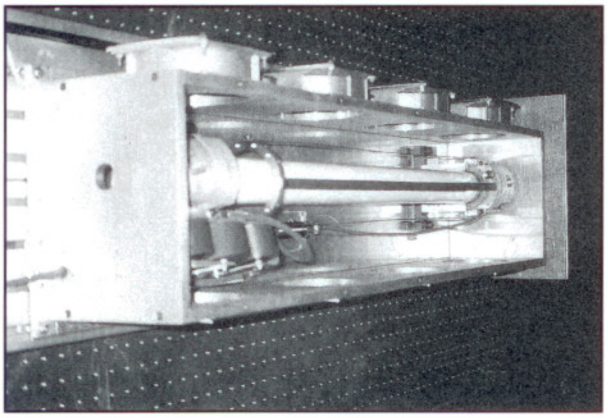

Fig.1: The prototype Copper Vapour Laser marking system used in the project

MATERIALS AND METHODS

The laser used in this project was the copper vapour laser* (CVL) (Fig.1) operating as a high repetitive rate and longitudinal discharge laser device. The laser is operated by charging a 2 nF capacitor to more than 10-12 kV and discharging it into a neon filled ceramic cavity. Operating at a high repetitive discharge rate, the ceramic cavity is heated gradually to a high temperature in the range of 1300 to 1600°C by the waste heat generated by the discharge. At this high temperature, copper filings placed inside the cavity vapourize which now takes part in the electrical discharge leading to the excitation and de-excitation of the copper atoms. With proper design of the electrical excitation circuit, two visible laser output wavelengths of 510.6nm and 578.2nm are obtained.

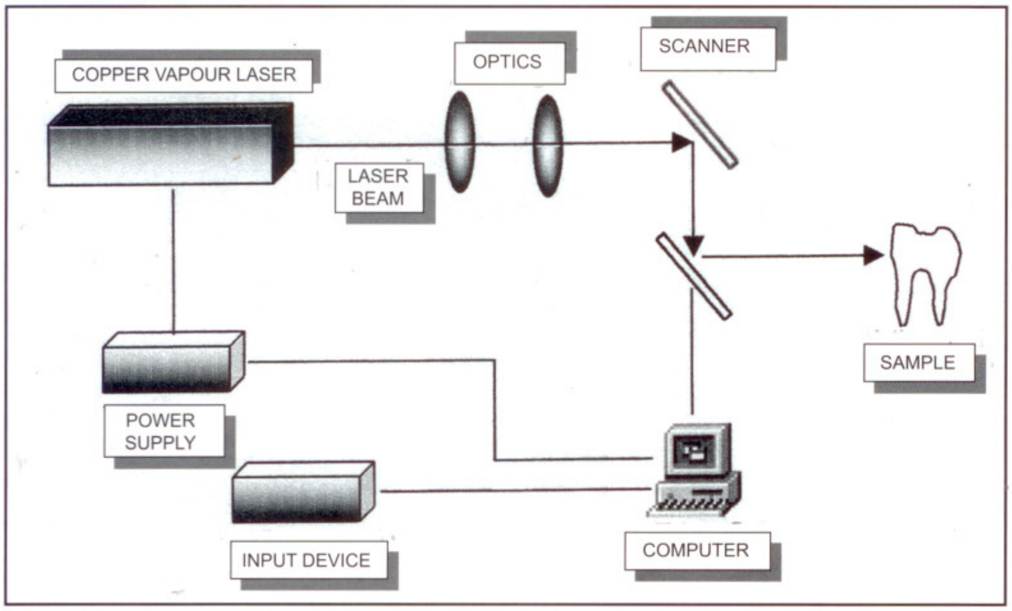

Fig.2: The schematic representation of the CVL marking system

The present CVL operates at 7 kHz with a peak power of 10 kW and pulse width of 20 ns with an average output power of 1.4 W (the experimental scheme is shown in Fig.2). A 5 cm diameter pyrex lens with a focal length of 12.5 cm is used as the focussing optical element. The lens (Fig.3) focuses the CVL beam down to a spot size of less than 10 mm in diameter and a two-axis scanner (Fig.4) delivers this focussed beam onto the material surface (Figs.5-7). The characters to be engraved were edited and entered into a personal computer using standard software converting the characters into a digital vector array. The microcomputer controlled the movement of the scanner and the firing of the laser. In between the different strokes in the writing of the characters as well as in the spacing of the characters, an accoustico-optic modulator is used to deviate the beam away from the scanned surface.

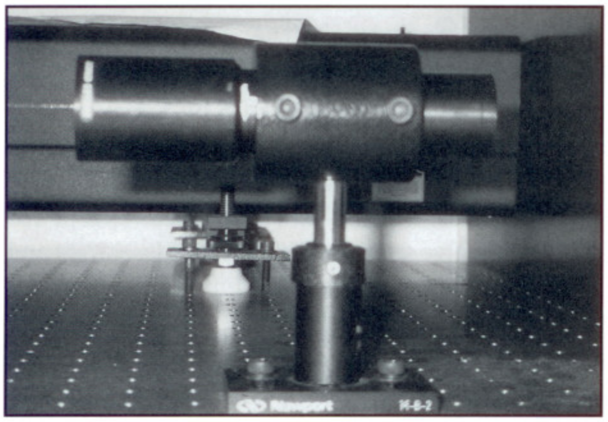

Fig.3: The laser optics of the system focus the CVL beam down to less than 10 μm

Fotontec Sdn Bhd, Kuala Lumpur, Malaysia

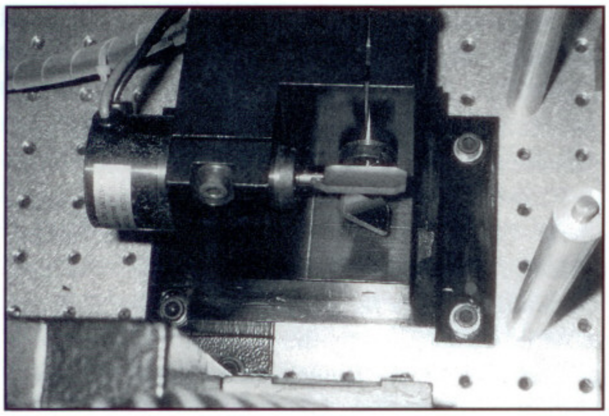

Fig.4: The two-axis scanner delivers the focussed CVL beam onto the material surface

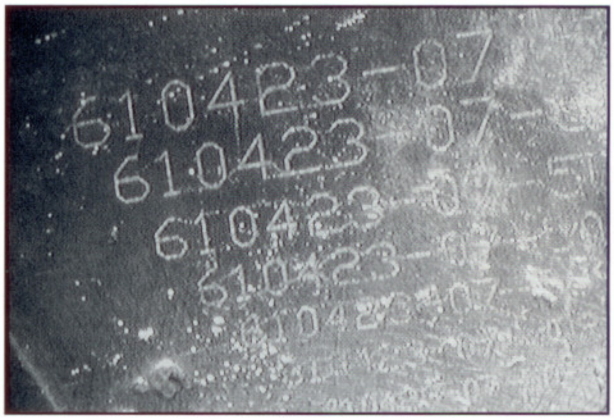

Fig.6: The sample ID marking of varying, decreasing size made on a cobalt-chromium test plate, seen under a stereo-microscope. The height of the characters in the third row is estimated to be 250 μm at 20X magnification

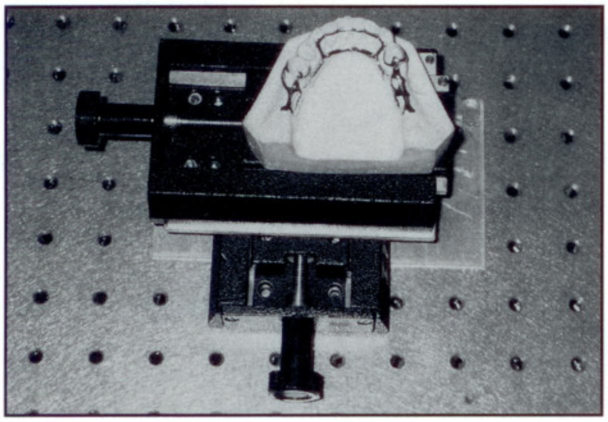

Fig.5: The cobalt-chromium denture to be marked, placed on the target stand

Fig.7: ID marking on the surface of an inlay, as seen under a stereo-microscope

RESULTS

The high directionality of the CVL makes it possible to achieve good focussing of the beam to a spot size of a few microns and thus delivers enough power to plasma-ablate the intended target surface. The engraving of cobalt-chromium alloy in prostheses, metal foils and other metal restorations is thus possible and effective. With fine engravings typically of less than 10 mm in width with an overall character height of around 200 mm, a large amount of data can be stored on the surface of the dentures or crowns. On the other hand, due to the generally curved surface of the dentures, engravings are made over a relatively small surface area of 5 by 5 mm^2 area to avoid undue beam defocussing effects. It was found that the plasma ablation process can effectively engrave most metallic alloy surfaces, except for highly reflective surfaces which reflect laser light and lead to inefficient engraving. Furthermore, due to the typically small energy of 1 mJ per pulse, the plasma ablation process is localised to the small spot area. The low energy laser pulses also produce insignificant shock waves to stress the material of the denture.

DISCUSSION

In any major disaster the rapid recovery and identification of victims' bodies are a priority. The victims may be of diverse nationalities and obtaining ante-mortem dental records for comparison with post-mortem records can be time consuming and difficult. It would therefore be very helpful if victims could be identified by features that are found on the body, be they inscriptions on a partial denture or on metal restorations.

The copper vapour laser enables clear and permanent engravings on the metal alloy surface to be made. As the size of the printing can be adjusted even down to microscopic level, more extensive personal particulars can be incorporated, including the wearer's full name, gender, nationality, personal identification number, country of origin and even telephone number of next-of-kin, e-mail address and other relevant information. This information facilitates speedy person identification and early notification of relatives. Although the initial cost of setting up a CVL is high, the cost of engraving is very low or negligible. The only drawback is the long warm-up time of the laser cavity of at least 45 minutes before laser radiation is emitted CVLs however incorporate a standby resistive heater to maintain cavity temperature overnight to avoid a cold start and laser emission can then be obtained after 10-15 minutes of electrical discharge of the laser tube.

CONCLUSION

Engraving on the metal components of dentures, fire-resistant foils or metal restorations ensures the durability of the mark because these components will withstand fire, which often follows a major disaster, or other degenerative processes. The CVL technology furthermore presents the option of miniaturizing the engraving so as to include considerably more information than is usually possible.

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