Part 1

FORENSIC DENTISTRY -
A LITERATURE REVIEW
Chapter 1
Forensic identification

1.1 Person identification

The United Nations Declaration of Human Rights stated in 1946 that all persons have a right to identity in life and death. Identification of unknown bodies is essential in modern societies for legal and humanitarian reasons. Most countries require by law that a death certificate be issued in order to settle such matters as disposition of an estate, collection on insurance policies and pensions, and remarriage of the spouse (Buchner, 1985).

A living person is recognised by many features, large and small, physical and behavioural. It is the combination of all these traits that distinguishes a person as an individual. During life, society records various data on all citizens,

'... in order to be able to discern between individuals, guarantee them their social rights, and protect them against injustice' (Keiser-Nielsen, 1980a).
When a person dies a great number of distinguishing features are lost and even physical features alter rapidly. Death usually occurs in circumstances where the link with surroundings and relatives is not broken. A death certificate is issued in due course and identity is not in question.

Sometimes a human body is found and death has occurred in an uncertain manner or as a result of criminal intent. The circumstances surrounding the death have allowed the links to known persons and places to be broken. Establishing the true identity of this person requires that a high level of scientific evidence be placed before a coroner before a confirmation of identity can be made.

'Identification of an unknown body or a living person may be defined as a statement based on certain characteristics which correspond to those of a specific person, and that bodily characteristics are really the only ones which determine with absolute certainty the identity of the body of a person' (Gustafson, 1966).

The elimination of a connection between a body and a missing person, while not achieving an immediate positive outcome, allows an investigation to refocus elsewhere.

'Contrary to identification, elimination is the safe and unambiguous outcome of a comparison and that it permits a clear statement that these two descriptions do not originate from the same individual' (Keiser-Nielsen, 1970).
Circumstantial evidence such as clothing and personal effects and documents found with the body may strengthen a case for identification but are not conclusive proof of identity. Such items can be borrowed or intentionally switched to induce incorrect conclusions as to identity. In transport incidents such as high-speed air crashes, personal articles are often dispersed by the violence of the impact and can become intimately associated with the body parts of others.

Visual recognition by relatives or acquaintances is a method used to identify the dead, which is used in most jurisdictions worldwide. In Australia it is only used where facial or other physical features are intact, and even then, other corroborative evidence of identity is required. Physical features rapidly alter after death and postmortem changes make visual recognition a limited option at best (Keiser-Nielsen, 1980a). Due to facial expression and skin tone changes after death, relatives will often fail to recognise a body (Craig et al, 1998). Cases have been reported where deceased victims' features were in good condition but they were incorrectly identified by women as their sons without any hesitation (Zugibe et al, 1996).

Fingerprint comparison of deceased persons with known records is widely accepted as being a very reliable method of identification (see below).
Dental structures and the configuration and distribution of fillings and fixed and removable prostheses are frequently used to match human remains of uncertain identity with the records of a known person.

Medical evidence such as deformities or birthmarks, scars from injuries and operations, prosthetic devices such as hip and knee joints and cardiac valves, cardiac pacemakers, skeletal features such as healed fractures and cranial suture closure can give supporting evidence of identity. Where antemortem records and/or radiographs of medical features are available, then comparison can provide very strong evidence for matching. Implanted or prosthetic devices often have a distinctive manufacturer's mark or serial number, which can be compared with a known person's surgical records. There was such a case where a burnt corpse was identified by a serial number on a prosthetic knee joint (Murray, Caiach, 1998). A West Australian coroner accepted an implanted intraocular lens as proof of identity when it was shown to precisely match the known specifications of the lens of a missing person (Isaacs et al, 1997).

Diagnostic and postoperative radiographs can be invaluable for comparison with postmortem films.
Serological-type comparisons can be useful in identification. This method is limited to supporting other evidence due to the majority of ABO, Rh and other antigens being common. Antigens may still be detectable in bone marrow with advanced decomposition (Buchner, 1985). They can be useful in elimination of possible subjects in an identification inquiry.

Recent advancement of DNA type-matching techniques makes this an increasingly useful method (Primorac et al, 1994). In Australia DNA matching is now acceptable for identification without any corroborative supporting evidence (Hill, 2000).

In a reported case, the usefulness of blood groups and advances in DNA profiling in an identification were described (Nagai et al, 1997). It was important that prompt identification was made to speed reconstruction of the crime and determination of possible other unknown victims. It was pointed out that DNA technology does not reduce the merits of dental identification, which remains a simple, effective and rapid technique in establishing identity.

1.2 Fingerprint identification
This method relies on the corpse having intact skin and an existing fingerprint record or the possibility of obtaining fingerprints left by the person before death for comparison with an unknown person. In cases of severe burning or decomposition, it is sometimes possible to obtain fingerprints from the internal aspect of the epidermis. Where no official fingerprint records exist, it is often possible to obtain latent fingerprints from the property of a missing person, such as hairbrushes, bottles and similar personal effects at home.

Some countries have extensive fingerprint records of the general population. For example, the United States of America has more than a quarter of the population's fingerprints recorded by the Federal Bureau of Investigation (FBI). In Australia, with a few exceptions, the only group with fingerprint records are convicted criminals.

Fingerprint matching has been used for almost 100 years as a reliable method of person identification. Fingertip patterns were first described by Malpighi in the seventeenth century as part of an anatomical study of the skin. Purkinje described nine basic fingerprint ridge patterns: transverse curve, central longitudinal stria, oblique stripe, oblique loop, almond whorl, spiral whorl, ellipse, circle and double whorl (Purkinje, 1823).
It was observed by Herschel and by Faulds that finger and hand print patterns were used by various illiterate groups in India and Japan in place of written signatures. The earliest use of fingerprints to solve a crime was made by Scottish physiologist Henry Faulds in Tokyo, where a dirty handprint was initially used to eliminate a suspect, and then later was matched to another suspect who confessed (Lane, 1992 a).

Galton, Vucetich and Henry all undertook scientific investigation into ways of classifying basic recurring configurations of ridges. Edward Henry (1898) published *The Classification and Uses of Finger Prints* which advocated a system based on five discernible patterns: arches, tented arches, radial loops, ulna loops and whorls, and a further five sub-patterns (Metropolitan Police, 2002). The Henry system was to become widely adopted by police forces as a standard text on practical fingerprinting. By the early twentieth century fingerprinting was becoming accepted by police forces and courts as a valid method of identification of persons (Moore, 2002).

For evidence of identity to be accepted, the resemblance must be shown to be convincing. Different legal systems have varying standards of what constitutes a convincing match. France requires 17 points of reference to coincide, Great Britain requires 16 points and Indian states vary from 6 to
12. The United States of America abandoned this concept on the grounds that there was no scientific validity in such a minimum requirement (Lane, 1992 c).

1.3 DNA identification

Deoxyribonucleic acid (DNA) is found in the nucleus and mitochondria of all cells except for mature red blood cells. DNA is a polymer composed of individual nucleotides, each consisting of a deoxyribose ring, a phosphate group and a nitrogen base and each nucleotide may contain one of four bases: adenine, guanine, cytosine or thymine, with such a polymer forming a single strand of DNA. When two single strands of DNA are linked, they do so across the nitrogen bases in complementary pairs ('base pairs'): adenine - thymine and guanine - cytosine, thus forming double stranded DNA. Molecular forces twist the complex structure to form a spiral, or double helix (McGilvery, 1970; Smith, 2001).

The sequences of base pairs along the DNA are different in all individuals and may be considered a 'code'. This unique code imparts genetic information on every characteristic, from species to personal traits such as eye colour and gender.
In 1984, Professor Alec Jeffreys established that DNA contained a code in the sequences of base pairs, which were unique to individuals. It was envisioned that this code could be used as a personal identifier (Lane, 1992b).

Patented techniques for splitting strands and sequences of DNA can give what is commonly termed a 'DNA fingerprint'. All western law enforcement jurisdictions now have access to databases which have been compiled from individuals of national, ethnic and cultural groups. These databases are used to calculate the prevalence of individual groupings of base pairs on the DNA strands.

In the identification of a dead body, a DNA fingerprint of the deceased can be compared with that of a near relative of interest. If there are sufficient similarities, as there are in related individuals, the profile frequencies of each segment of the DNA code can be calculated and an overall prevalence of the particular DNA fingerprint in a certain population can be estimated. A chance of random error in assuming that the DNA samples originate from the same source can be stated.
Chapter 2
The development of forensic dentistry

2.1 Forensic dental identification

Dental identification of unknown bodies is a well-known and widely used method of identification (Brown, 1984). It is especially valuable when other means of identification such as visual recognition and fingerprints are not possible. Dental identification relies on the comparison of antemortem and postmortem records (Clark, 1994).
The value of dental identification is only as good as the quality of antemortem records permits. On the other hand, the quality of postmortem dental remains can severely limit the data available for matching. Difficulties arise when there is serious damage to, or complete destruction of, restorations and disintegration of dental tissues as the result of extreme physical or environmental changes. Failure to recover all teeth and their included restorations, as well as incomplete dental records, may frustrate the identification process (Brown, 1984).

With the 32 teeth of the adult dentition, each with five surfaces, there is a large number of possible combinations of restorative materials, missing teeth, carious lesions and prostheses. There is also a multitude of anatomical features, along with restoration outlines, visible on radiographs. It is the comparison of these features, with records of a known person, which forms the basis of dental identification.

In Australia presently, the dentitions of young adults typically have a minimum of dental restorations. Although there are not the characteristic arrays of restored teeth of the earlier decades, orthodontic treatment and wisdom tooth surgery is common. Orthopantomogram (OPG) radiographs are often taken for assessment of wisdom teeth and orthodontists take and
keep comprehensive radiographic, photographic and plaster model records. Dental identification by comparison of tooth and anatomical outlines from an OPG is often conclusive. A set of plaster models retained by an orthodontist can give invaluable data for comparison in identification, as can, to a lesser degree, photographs.

The elderly may have grossly depleted dentitions or even edentulism with full dentures. With 63% of Australians over age 74 years being edentulous in 1987-88 (Barnard, 1993). Dental identification in such cases may rely on configurations of missing teeth, design of dentures or recovery of unworn dentures from the domicile of a missing person, which can then be matched to the remains. The natural dentition of an elderly person may exhibit a tertiary level of restorative history with 60 or 70 years of increasingly complex repair evident. A common problem for the forensic odontologist is that edentulous or near-edentulous persons may not have attended a dentist for many years and records of any treatment may have been lost or may be irretrievable.

It is widely acknowledged that the marking of dentures at construction is a very cost-effective method of identifying persons, both living and dead. For matters of personal freedom and cost, most dentures are not marked (Sathyavagiswaran, 1993; Berry et al, 1995). Denture marking is useful for
the elderly in an institutional care setting, especially those with dementia. In these people, the minimal cost of marking dentures more than offsets the considerable expense of locating or remaking lost dentures (Richards et al, 1992).

Where identification of a person is uncertain and DNA typing is employed, costs in excess of $500 are incurred (Griffiths, 1998). A common event is where a demented elderly person wanders away from home, becomes lost and dies in the open where the body is not found for some time. Denture marking is of immeasurable value in such cases where often no identifying personal effects or documents are carried and advanced decomposition may have ensued.

A dental laboratory record will often show denture tooth mould numbers and shades and characterising features such as gold inlays. Such a record, when retained by a laboratory or dentist can be invaluable in an identification (Taylor et al, 2002).

Socio-economic and ethnic groupings and, as mentioned, age, have a significant bearing on patterns of dental treatment (Spencer et al, 1994; Spencer et al, 1996). Regular and conservative dental treatment is more prevalent in higher income earners and urban dwellers. These people are
more likely to have intact dentitions and available dental records. Aboriginal Australians and people with non-Australian backgrounds may exhibit a distinctive dental profile, both restoratively and anatomically. In such cases, antemortem records are often nonexistent or impossible to obtain.

### 2.2 Disaster victim identification

In incidents involving large numbers of deceased victims, dental identification is consistently the most successful. Of fire victims, 61% were identified by dental means with another 31% being assisted by dental evidence (Andersen et al, 1995). In the Zeebrugge, Piper Alpha, Lockerbie and Kegworth disasters 80% were identified by dental means. The identification of victims of the 1997 Thredbo landslip disaster in the Australian Snowy Mountains was based on dental comparisons in the majority of cases (Griffiths, 1999). Of the victims of the Bali bombings in October 2002, 60% were identified by forensic dental methods (Griffiths, 2003).

The International Criminal Police Organisation (Interpol, 1996) has set a protocol for dealing with identification of bodies from small to large-scale
disasters. There are four major phases involved in victim identification, namely:

- **Phases 1 & 2**
  Recovery and examination of bodies to establish reliable postmortem evidence from the deceased (PM information)

- **Phase 3**
  Procurement of antemortem information for possible victims (AM information)

- **Phase 4**
  Reconciliation of AM and PM data to positively identify each body.

Disaster victim identification procedures may also be used in small incidents (DVI Procedures Manual, 1999) and even with a single unidentified person (Australian Disaster Victim Identification National Guidelines, EMA, 1996).

Until the 1970s, transport disasters rarely resulted in more than 150 deaths. In their historical incident list, Kenyon International Emergency Services records numbers-per-incident at well under 50 deaths in aircraft incidents dating from 1929 to the early 1960s. With the advent of larger airliners and an increasing acceptance of air travel worldwide, there were significantly higher death tolls reported, with numbers often in the several 100s by the 1970s.
Mass disasters still had to be dealt with before the age of the microcomputer. When dealing with large numbers of bodies which are typically disfigured, matching antemortem dental records with remains becomes a formidably time consuming task even with adequate numbers of trained personnel. The relatively simple process of comparing dental records with a body becomes onerous with, say, 30 deceased. A single record would need to be compared with the dental remains in turn to search for a match. In fact, the remains are usually sorted where possible into such groupings as: gender, dentures, no dentures, fillings, no fillings, and then a record needs only to be compared among members of the appropriate sub-group. In a wide-bodied airliner crash it is common to have 200 to 400 deceased, and in this situation, even the grouping of remains still leaves a huge task for forensic odontologists faced with matching records. The focus of the world’s news media and the pressure from politicians and relatives for speedy repatriation of remains places enormous strains on human resources, both physically and emotionally.

The problems are magnified where only fragmentary and dispersed remains are recovered such as in high-speed aviation crashes. A number of computer programs have been developed to facilitate efficient matching and elimination (Lorton et al, 1988; Arneman, 1991). Such
programs can allow rapid sorting and provisional matching of remains with antemortem records.

The CAPMI (Computer-Assisted Postmortem Identification) system was developed by the United States Army to facilitate rapid identification of human remains (Lorton et al, 1988). Common dental features such as filled tooth surfaces, types of restorative materials and root canal therapy are used in this program, whereas evidence of caries is not, because of unreliability in diagnosis due to the wide variability in operator judgement in its detection and quantification.

CAPMI has been used in many large-scale disasters and found to be effective. In a 1987 crash in Poland the system was used in a list of 183 deceased passengers and crew (Lorton et al, 1988). The CAPMI software was altered to allow for tallies of mismatches to be reported which was found to be useful in this case due to the high level of fragmentation of bodies and incompleteness of available records. Final matching when using a computer system in disaster victim identification will always be carried out manually by a forensic odontologist as the minute detail and judgement involved are beyond the capabilities of current computers.
With a view to dealing with dental identifications in a mass disaster, a
dental classification system has been devised whereby each victim was
given a number derived from the dentition as follows. The premolars were
used as they were seen to be the teeth most likely to be present and
reliably identifiable in a body. Antemortem records were examined and
the same system was used to calculate a number from the status of the
person's dentition in life. A number between 0 and 9 was designated for
the various states possible for each tooth and a gender prefix was used. A
number, such as M-6757.6957, could describe the whole premolar dentition
for example. In practice, the system worked well but in one trial of 560
records, 8% of patients had a configuration of 5555.5555 (all premolars
present and unfilled) and 11% had a configuration of 9999.9999 (prosthetic
replacement of all premolars). In a real disaster victim identification
situation even this would provide a sorting criterion or evidence for
elimination of those cases (Haines, 1971).

Chapter 3
The dental record

3.1 Dental records

A dental record of a consultation completed by a dentist ideally consists of a dated written account of reasons for presenting, observations on examination, results of tests, treatment and advice given. In private practice, accounting details are usually also included as a part of an entry. In conjunction with the written record, there is often an entry made, in the form of symbols, on a diagrammatic chart of all the teeth to represent the work done on a particular tooth. The quality of records kept varies from meticulous to cryptic and, sometimes, virtually nonexistent. Sometimes, a dental record entry made in a private practice will show only health insurance item numbers to describe treatment with no mention of the tooth or tissues treated. Such records have little forensic value. Even so, such records sometimes prove invaluable as a means of identification (Gustafson, 1958). Standards of dental data recording do vary in different countries (Clark, 1994).

Occasionally a meticulous practitioner will chart the existing restorations and missing teeth and it is these records which can provide a qualitative
and quantitative set of data for comparison in an attempt to identify a
deceased person. Systematic precautionary antemortem dental recording
has long been practised for all flying personnel in the Scandinavian
Airlines System Danish sector (Keiser-Nielsen, 1980a). Defence forces
personnel in Australia have full restorative and dentate status recorded
on entry.

Australia is moving towards legislation in all states to impose a minimum
statutory standard for dental data recording and preservation of those
records (AEMI, 1997).

### 3.2 Dental charting systems

In any scientific community, attempts are made to standardise a
nomenclature but it seldom happens that an 'official' nomenclature is
recognised by all members in the field (Alt, Turp, 1998). In anatomy, a
standard Latin nomenclature was first compiled in 1895. Unlike the
anatomical nomenclature, tooth-numbering systems in use today are
precise

Zsigmondy proposed the first tooth numbering system in 1891 known as
the Symbolic System. The mouth was divided into four grids in frontal
view, with each quadrant providing a shorthand method of designating the quadrant and tooth number, for example 5 for upper right second premolar. The primary dentition was depicted with a similar grid using Roman numerals I, II, III, IV, V to number the teeth from the midline distally (Figure 3.1).

\[ 8 \ 7 \ 6 \ 5 \ 4 \ 3 \ 2 \ 1 \ 1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \]
\[ 8 \]
\[ 8 \ 7 \ 6 \ 5 \ 4 \ 3 \ 2 \ 1 \ 1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \]
\[ 8 \]
\[ V \ IV \ III \ II \ I \ I \ II \ III \ IV \ V \]
\[ V \ IV \ III \ II \ I \ I \ II \ III \ IV \ V \]

**Figure 3.1** The Zsigmondy notation (Source: Clark DH, 1992)

This system was modified by Palmer in America who used A, B, C, D, E to describe the deciduous teeth (Figure 3.2).

\[ E \ D \ C \ B \ A \ A \ B \ C \ D \ E \]
\[ E \ D \ C \ B \ A \ A \ B \ C \ D \ E \]

**Figure 3.2** The Palmer deciduous modification (Source: Clark DH, 1992)
Cunningham sought to remove the possible confusion of using a grid and devised a straightforward numbering method. The teeth were numbered from 1 to 32 starting from the upper left quadrant and progressing clockwise around the arch. The primary teeth were described in similar fashion but using A, B, C, D and E. This method of charting was called the Universal system (Figure 3.3) and although it is used widely in the USA, it has not been universally adopted as many other systems are also in use (Goodman, 1967).

```
1  2  3  4  5  6  7  8  9 10 11 12 13 14  \text{Permanent}
16
32  31  30  29  28  27  26  25  24  23  22  21  20  19  18
17

\text{A B C D}  \text{E F G H I J}  \text{Deciduous}
\text{T S R Q}  \text{P O N M L K}
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**Figure 3.3** Cunningham’s (Universal) notation (Source: Clark DH, 1992)

The US Navy system (Figure 3.4) is a modification of the Universal System with the reversal of the number order in the lower teeth.
In 1902 Haderup published a system (Figure 3.5) using plus and minus signs to indicate the position of the teeth in the arch, the teeth being numbered 1 to 8 from the midline for the permanent and 01 to 05 for the deciduous teeth.

<table>
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<th>Permanent</th>
<th>Deciduous</th>
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<td>8+ 7+ 6+ 5+ 4+ 3+ 2+ 1+ 1+ 2+ 3+ 4+ 5+ 6</td>
<td>05+ 04+ 03+ 02+ 01+ 01+ 02+ 03+ 04</td>
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<td>+7 +8</td>
<td>+05</td>
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<tr>
<td>8- 7- 6- 5- 4- 3- 2- 1- 1- 2- 3- 4- 5- 6- 7</td>
<td>05- 04- 03- 02- 01- 01- 02- 03- 04</td>
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<td>-8</td>
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Today there are many systems in use in each country. The Federation Dentaire Internationale (FDI) in 1970 originated the two-digit system of recording teeth (Figure 3.6) and although it has gained wide acceptance, there are still 30 tooth notation systems in use worldwide (Rotzscher, 1992). With the increasing mobility of individuals across international boundaries, dental records are often sought from other countries or states where unfamiliar notation systems are used. In 1971 the FDI system was adopted by the American Dental Association, the International Standards Organisation, the International Association for Dental Research, and the World Health Organisation (Beale, 1991). Interpol also accepted the FDI system and this standardised the transmission of dental data between police jurisdictions worldwide.

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The designation of the surfaces of a tooth is usually accepted to be five, that is, the front, back, outside, inside and occlusal (or incisal in anterior teeth). The most common method of describing these surfaces is by the Latin anatomical method, that is, mesial, distal, buccal (or labial for anterior teeth), lingual (lower teeth) or palatal (upper teeth) and occlusal respectively. This system is practised in all countries but France, Belgium and the USA use "vestibular" to describe the buccal surface (Frykholm, Lysell, 1962). Other variations use palatal to describe inside surfaces of upper teeth and ‘li’ and ‘la’ to distinguish lingual from labial. These codes refer to the whole of the tooth surface so described. Where a feature exists on the gingival aspect of a tooth surface, a second letter, ‘g’, has been used sometimes to indicate this, for example, ‘bg’.

Denmark, Finland and USA have also used a numerical code based on the five surfaces although the number sequence varies. In Germany dentists sometimes use an older system with ‘c’ for central to describe the occlusal surface as well as the usual ‘o’. The United Kingdom and some other

Figure 3.6  FDI notation (Source: Clark DH, 1992)
countries may also use a combination of symbols such as lines and dots to indicate surfaces.

In Australia, USA and the United Kingdom, GV Black’s classification of cavity outlines is sometimes used, mainly in dental schools (Table 3.1). Most countries also use an odontogram, which is a representation of all the teeth diagrammatically in either anatomical or schematic form.

<table>
<thead>
<tr>
<th>Black’s class</th>
<th>occlusal, pits, fissures</th>
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<tr>
<td>I</td>
<td>proximal, premolar and molars</td>
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<td>II</td>
<td>proximal, anterior</td>
</tr>
<tr>
<td>III</td>
<td>proximo incisal</td>
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<td>IV</td>
<td>gingival</td>
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In reviewing the history of the development of the FDI dental recording system, Keiser-Nielsen (1974) stressed that this system was not developed and recommended for forensic dental purposes, but to generally improve professional communication of dental matters worldwide. Now, over 25 years later, the FDI system is the closest there is to a truly international notation with wide acceptance, even if in many countries individual
dentists still may favour one of the multitude of known systems and some unknown ones as well. The adoption of the FDI system for the Interpol Disaster Victim Identification forms ensures that this is in fact the standard system for the transference of forensic dental information internationally.

### 3.3 Dental characteristics

The normal complement of teeth in an adult human is 32. Teeth may be lost, often through dental disease or trauma, but also due to intent, such as for orthodontic purposes, or prevention of anticipated problems as with the removal of third molar teeth. Configurations of tooth-loss impart characteristics to a person's dental status.

For the whole of the twentieth century in western societies, teeth have been subject to restorative treatment where artificial materials have been used to repair, replace and enhance the teeth. With a tooth having five surfaces, which may be restored with many methods and materials, a person's dentition can rapidly become distinctive by virtue of restorative treatment alone. At the macroscopic level, a tooth has no means of regeneration apart from artificial repair. As the life of a person progresses, the likelihood of restorative procedures to individual teeth increases. It is
this irreversible process that characterises teeth and it is the combinations of such treatment, which can impart a unique overall dental status to an individual, which is so frequently used to identify the dead.

The principle of matching recorded dental data to an unidentified person depends upon the levels of probability involved in the occurrence of that data. A physical ‘characteristic’ may be defined as a feature, which has an improbability of occurring. Accordingly, such a characteristic would be known to occur in less than 50% of all cases, and the more infrequently the more characteristic (Keiser-Nielsen, 1980b). However, he demonstrates that while a given feature may have to be rated as uncharacteristic, its combination with another uncharacteristic feature may well bring us back into the realm of a combined characteristic. For instance, we could select from among antemortem and postmortem data a corresponding feature, for which we knew the frequency of occurrence to be 60%, and thus an uncharacteristic feature, and could combine it with another similarly uncharacteristic feature of a 60% occurrence. To calculate the likelihood of both these features occurring in one individual, the individual probabilities, expressed as fractions, can be multiplied together, that is: $6/10 \times 6/10 = 36/100$, or 36%. This means that there is a 36% chance of a random occurrence of both these traits, and that, by the above definition, becomes a characteristic feature (See 8.2, Evaluation of a match).
In another study, dental features have been described as ordinary (greater than or equal to 10%) or extraordinary (less than 10%), based on their occurrence in Danish reference populations (Andersen et al, 1995).

When calculating the combined prevalence of dental traits, the forensic odontologist must be aware that if several individual traits have a common cause, then their combined occurrence may be more likely than if they occurred independently. For instance, a missing upper first premolar, in an intact dentition, may give rise to an increased likelihood that the contralateral tooth is also missing due to the common practice of removal of these teeth for orthodontic purposes.

'In determining the probabilities, care must be taken that the different events used in the combinations have separate backgrounds of causation.' (Dahlberg, 1957)

In a recent study in the United States of large cross-sections of both military personnel and civilians, dental patterns were found to be highly individual (Adams BJ, 2003a; Adams BJ, 2003b). These datasets contained whole-mouth chartings of individuals including surface based filling information and specific missing and unfilled tooth data. When fully dentate individuals without any restored teeth, and edentulous individuals were excluded, whole-mouth patterns or even patterns using
only the posterior teeth were highly distinctive. The low probability of finding random matches did not seem to deteriorate significantly when only generic (ignoring surfaces filled) data was used. Statistical analysis of the prevalence of empirical patterns of missing, filled or unfilled teeth showed that the levels of diversity were comparable with the highly individual results obtained with mitochondrial DNA sequences used in identifications. Adams does not calculate individual tooth status prevalence but is able to search the datasets for a whole-mouth or mouth fragment dental pattern to give the actual prevalence. This obviates the need to consider the levels of independence of various individual traits within a mouth.
The origin of the definitive connection between law and medicine may be dated from the publication of the Codes of Justinian around AD 530, in which it was provided that medical knowledge should be utilised in the adjudication of certain legal cases.

4.1 The coronial system

Coroners inquire into the circumstances surrounding deaths, which are reported to them. The coronial system of investigating death originated in aspects of English law over 800 years ago. In Norman times, a coroner needed to determine the identity of a corpse so that appropriate taxes or fines could be levied (Ranson, 1998).
In Australia most deaths occur in a person's home and these deaths are usually due to natural diseases. In most of these cases a medical practitioner is associated with the deceased and has attended them during their last illness or in the recent past (Ranson, 1997). In such a case the attending medical practitioner acts as a death investigator, and if he/she believes they know the cause of death then they can issue a death certificate. There are some deaths which, due to their circumstances, are required by statute to be reported to the coroner.

The Coroners Act 1995 (No. 73 of 1995) in Tasmania defines a reportable death as being a death -

'... (iv) that appears to have been unexpected, unnatural or violent or to have resulted directly or indirectly from an accident or injury; or
(v) that occurs during anaesthesia or sedation; or
(vi) that occurs as a result of anaesthesia or sedation and is not due to natural causes; or
(vii) the cause of which is unknown; or
(viii) of a child under the age of one year which was sudden and unexpected; or
(ix) of a person who immediately before death was a person held in care or a person held in custody; or
(x) of a person whose identity is unknown; ...'

Statutes regarding reporting of deaths to a coroner are similar in all states of Australia.

Nowadays, the role of the coroner is a very public one and the community relies on the coroner to determine the identity of the deceased person,
inquire into the time, place, cause and manner of death, refer the matter to
the Department of Public Prosecutions in relation to cases where it
appears that an indictable offence may have been committed, and notify
appropriate authorities or expose matters of public importance where it is
deemed necessary (Griffiths, 1996).

In Australia, recognised forensic odontologists are a part of the coronial
system. They may be issued with a subpoena to attend the Coroner's,
District or Supreme Court. Occasionally a subpoena may direct that
evidence be given in a written form.

4.2 Expert testimony

In legal proceedings, people may be called to give evidence as witnesses-of-fact, as professional witnesses or as an expert witness.

A witness-of-fact, or an 'ordinary' witness, testifies directly as to some fact
within their knowledge, thus giving only factual evidence. The opinion of
this witness is inadmissible as evidence and will be disregarded
(Griffiths, 1996). For example, a bystander may witness an incident where
a child crossing a road is struck by a car. The witness-of-fact may be asked
in court to describe what they saw. If the witness then offers an opinion
that the car was in an unroadworthy condition, and that this contributed
to the incident, then the testimony would not be heard because the witness is not recognised by the court as an expert automotive engineer.

A professional witness, in legal terms, is identical to a witness-of-fact, except that the facts are obtained in the course of professional activities rather than seeing something while walking down the street. An example is a dentist called to give evidence in a malpractice suit against another dentist. Courts tend to allow more tolerance as to how far this witness may offer opinions, but generally the professional witness will limit their testimony to facts such as their own treatment and notes pertinent to the case. Definitive expertise in such a case may, in all likelihood, be obtained from a dental specialist or academic with higher qualifications, in fact, a true expert witness.

'The expert witness brings special skills to bear on the issue in question, and almost always give an opinion on facts adduced either by themselves or by others. The role of the expert witness was once defined by a Scottish judge as being to "furnish the judge or jury with the necessary scientific criteria for testing the accuracy of their conclusions, so as to enable the judge or jury to form their own independent judgement by the application of these criteria to the facts proven in evidence."' (Clark, 1992)

The right of medical practitioners to be treated as experts able to give opinions has long been recognised (James, 1955).

'The determination of whether a witness is properly qualified as an expert is left to the 'sound discretion' of the trial court'.

The so-called 'helpfulness' test allows that,
'... experts, by virtue of experience or training, may provide an understanding more thorough or refined than that provided by ordinary experience. Opinions are beyond a charge of perjury. Data reasonably relied upon by an expert may come in many forms, sometimes not by direct experience. In Leis v Rego Co (USA) it was noted that experts may reasonably base their opinions upon discussions held with other experts.' (Slovenko, 1993)

The admissibility of evidence given by experts and based on material derived by other experts is also well illustrated in a court of appeal judgement:

'In the context of evidence given by experts it is no more than a statement of the obvious that, in reaching their conclusion, they must be entitled to draw on material produced by others in the field in which their expertise lies. Indeed, it is part of their duty to consider any material which may be available in their field.' (R v Abadon, 1983)

4.3 Understanding of scientific evidence

When a forensic scientist gives evidence in court, the jury, judge and advocates, most likely people with little or no scientific training, need to hear and understand the testimony (Tanton, 1979). These people must then be able to not only understand what the expert said, but the significance of the expert's testimony. They must also decide whether the expert is competent and honest.

The close involvement of the statistician is desirable when attempting to present conclusions drawn from statistical forensic data (Aitken, 1983).
Lay persons can then comprehend and objectively consider data containing figures.

'If a tribunal cannot understand the derivation of certain scientific conclusions it must, like St Thomas, remain a "doubting tribunal" and thus reject the evidence as inconclusive.' (Gundelach, 1989)

This situation is common to some scientific comparisons such as the interpretation of fingerprints, footprints and ballistics.

In an Australian case, (R v Carroll, 1985), a jury's verdict of guilty was quashed on appeal because the three judges were unconvinced of the reliability of three expert odontologists' opinions that the marks on a murdered baby's thighs were actually caused by Carroll's teeth. On the other hand there is much expert evidence which is accepted without fuss, such as supposedly accurate determinations by a medical practitioner on time of death.

'The evidence of a forensic expert is only admissible, being opinion evidence, where the field of knowledge in which the expert witness professes expertise is outside the ordinary experience of a person and whether the witness has sufficient expertise in such field as would enable him/her to assist the tribunal.' (Gundelach, 1989)

The use of expert witnesses is increasing as a majority of legal cases involve procedures or products beyond the understanding of a judge or jury (Slovenko, 1993).
There are numerous examples of civil and criminal lawsuits in which the failure of the trial judge and/or the attorneys to appreciate the significance and importance of crucial forensic scientific evidence resulted in grave injustice or unresolved controversy (Wecht, 1996). In his review of animal bitemark evidence in the Australian trial (Queen v Chamberlain, 1984), for submission to the Commission of Inquiry, expert evidence was criticised and it was emphatically noted,

'... the criteria on which witnesses with special knowledge are selected to examine materials, prepare reports and give evidence in court are in fact at present seriously inadequate.' (Fearnhead, 1986)

Expert 'opinion' is likely to remain just that, and lawyers are always keen to see if it 'comes up to proof'. Under the Frye standard (Frye v United States, 1923), it is not enough that expert witnesses are prepared to testify that a technique or procedure is valid, or that the court believes that the evidence is helpful and reliable - it must meet general acceptance, that is, consensus in the scientific community (Slovenko, 1993).

The passing of the 1975 Federal Rule of Evidence 702 in the United States set a more flexible test for the admittance of expert testimony. In the Daubert v. Merrell Dow Pharmaceuticals case, (US Supreme Court, 1993), it was held that Rule 702 supersedes the test articulated in Frye and set a
number of criteria which a trial judge could use as a guide when assessing
the admissibility of expert evidence. Amongst these criteria were,

'... (1) whether the technique can be, and has been, tested; (2) whether it has
been subject to peer review and publication; (3) the known or potential rate of
error; and (4) whether the technique has been generally accepted.

The court characterized these factors as "general observations" and declined to
set out a definitive checklist or test.' (US Supreme Court, 1993)

4.4 Fingerprint evidence

Challenges to the scientific status of fingerprint techniques were made
long before their universal acceptance by law enforcement authorities.
The first challenge to the reliability of fingerprint evidence in the United
States was mounted in 1911 against the death sentence in a murder case.
The Supreme Court of Illinois ruled that there was a scientific basis for the
system of fingerprint identification and dismissed the appeal.

Even recently, it was asserted that fingerprint expertise was based on 'art',
not science, as, it was claimed, evaluating fingerprints was a subjective
process (Daubert v. Merrell Dow Pharmaceuticals, 1993; Kumho Tire Co.
v. Carmichael, 1999; United States v Byron C Mitchell, 1999). In the latter
case, the court took notice that,

'Human friction ridges are unique and permanent throughout the area of the friction
ridge skin including small friction ridge areas.' (US Attorney's Office, Eastern
District, Pennsylvania, 1999)
4.5 DNA evidence

Statistical evidence concerning the reliability of DNA matching is based on the use of the product rule (see Chapter 8.2). This has been challenged and upheld on numerous occasions in jurisdictions worldwide. It is the way in which the product rule is used that is often the reason for the large discrepancies so commonly found in evidence from different statisticians and scientists. Some methods, in an attempt to give defendants the benefit of the doubt, use purposely high estimations (Lander, 1991).

During the last two decades since the advent of DNA typing technology, there have been many disputes between scientists and legal experts as to the validity of the statistical methods used to calculate DNA random match probabilities. The debate continued in case after case where courts were given conflicting estimations of the frequencies which often varied enormously, as in one murder case where several expert witnesses gave DNA statistics of $1/ (465 \text{ million})$, $1/ (1.1 \text{ trillion})$, $1/ (466 \text{ billion})$, $1/ (465 \text{ million})$, $1/ (1/1 \text{ billion})$ (People v. Miller, 1996).

A United Kingdom news agency recently admitted that a man who had been identified as the culprit in a burglary by DNA matching to a national
database was later found to have been falsely accused. His DNA profile was found by searching the database of 700,000 persons where he appeared due to a previous arrest. The matching was done on 6 loci of the DNA molecule but as the man now had Parkinson's disease, could not drive and could barely dress himself, his lawyer maintained that it was impossible that he had committed the crime and demanded a ten-loci test (a locus is a specific site on a chromosome). In this case the police had asserted that there was only a one in 37 million chance that they were wrong. In fact, DNA matches based on only 6 loci are not conclusive and the extra four loci proved that he was not the culprit (Moenssens, 2001).

In cases of identification where other evidence of identity is present, a coroner may accept DNA evidence based on as little as three loci where the genotype frequency was calculated to be as low as $5.79 \times 10^{-3}$ ($1/173$) (Sweet, Hildebrand, Phillips, 1999).

### 4.6 Dental evidence

It is said that the sole duty of the medical witness is,

'... to present his medical observations and to construct reasonable deductions from them. Their aim should be the truth; there should be no taking of sides and no evasion. The doctor is called to help the court come to a correct decision'.

(Simpson, 1969)
The forensic odontologist is now well established as one of many specialists who provide important services in courts of law.

"Clinical forensic medicine involves the collection, critical evaluation, and presentation of medical evidence for use in the civil and criminal arenas. The term "forensic" has come to be used as an adjective to identify a growing number of subspecialties of medicine, as well as other scientific fields that may provide scientific evidence in courts of law" (Wecht, 1996).

It is essential that impartiality be maintained in the presentation and interpretation of evidence. Because he/she usually works closely with the police and forensic pathologist, the forensic odontologist must always be wary of defending the prosecution view of the evidence. The police on the other hand are very much on the prosecution side, as it is their view of the evidence, which often leads to the charges being heard.

In the courtroom, the forensic dentist often relies on personal judgement when giving evidence on dental characteristics. It is pertinent for defence and prosecution counsel to ask how common are certain characteristics in the general population (MacFarlane, MacDonald, Sutherland, 1974). Where a large sample has been taken such as the National Oral Health Survey Australia (1987-88) it is typical to record full mouth data, but only as totals of decayed, missing and filled teeth (DMFT), in single individuals. Age groups in this survey were broad. Thus, a forensic
dentist giving evidence may only provide a general subjective assessment on whether a particular restorative trait, for example, is characteristic, and to what degree.

'As only little statistical information, for example, on the frequency of the different types of fillings is available, the conclusion will usually mostly be based on the personal experience and judgement of the forensic odontologist.’ (Solheim, Schuller, 1999)

In 1958 Gustafson reported that there were no data existing

'... concerning the degree of certainty it is possible to obtain from a comparison of dental records.'

Doubt may remain even though the data from records corresponds with data taken from a body. This may happen in those cases where very little dental treatment has been given and where the treatment is not out of the ordinary.

An 'Identification Strength Scale' has been proposed in an attempt to address the problems faced by forensic odontologists giving evidence in court. This is a six-point scale:

5. Positive, within reasonable dental (scientific) certainty.
4. Very probable, highly probable, highly consistent, most likely.
3. Probable, consistent with.
2. Presumptive by exclusion.
1. Cannot exclude.
0. Mismatch, unidentified.’ (Dailey, 1987)
These terms were, and still are commonly used by forensic odontologists when describing the level of likelihood of an identification. The subjective limitations of such language naturally lead a lawyer to ask for a more definitive statement based on a number, such as a percentage.

There has been a tendency for some forensic odontologists to refer to the number of points of correspondence when matching remains to dental records. This probably has its origins in the practice of fingerprint comparisons where it is usual to declare a match when a certain number of points of concordance are encountered (see 1.2 Fingerprint identification).

Keiser-Nielsen was advocating such an approach in 1970, stating that dental identification requirements were exactly like those used for fingerprint identification and that 'safety of judgement' can only be attained by,

'... concentrating on an adequate minimum number of concordant features which, in its given combination, is large enough to remove the risk of duplication behind the statistic confidence limit and into practical negligibility.' (Keiser-Nielsen, 1970)

He later settled on a minimum of twelve concordant features, even if those features are not 'singular', to place a dental match beyond reasonable doubt (Keiser-Nielsen, 1977).
The adoption of this criterion for dental identification has potential pitfalls; for instance, there is a wide range of acquired dental traits and the prevalence of these varies greatly. An identification once was rejected when only two concordant dental features were present. Closer analysis revealed that this person was of middle age and had a full dentition with only two fillings. Here the dentition was very characteristic, as in this population the lack of restorations in a complete dentition in this age group was exceptional (Hill, 1989).

The United States military similarly advocates the use of individual judgement in weighting the importance of individual traits in identifications,

'For the dental findings, it becomes a matter of professional judgement. There are no set number of points that must agree to merit identification. It is possible that there is only one point of agreement (with no definite disagreements) that would prove the case beyond a shadow of doubt. ... On the other hand, there could be a number of points of agreement, yet the dentist might not be absolutely certain.' (Jerman, 1981)

In conclusion, it would seem that a forensic dentist, as an expert witness, ideally would have at hand, or be able to acquire dental trait prevalence data relevant to the population group to which an identification case belonged. Thus, they would be able to give qualified evidence to a tribunal seeking to judge the validity of the conclusions.