A quantitative method for the forensic evaluation of bitemarks.

Phrabhakaran Nambiar, B.D.S., B.Sc.Dent. (Hons.)

Forensic Odontology Unit,
Department of Dentistry,
The University of Adelaide,
Adelaide, South Australia

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A. PREFACE

1. Declaration

This thesis is the report of original work and the results presented have not been submitted for the award of any other degree or diploma in any other University. To the best of my knowledge, this thesis does not contain any material previously published or written by another person, except where due reference is made in the text. The research described in this thesis represents the unaided work of the candidate, except where otherwise acknowledged. I consent to this thesis, if accepted for the award of the degree, being made available for photocopying and loan.

Phrabhakaran Nambiar, B.D.S., B.Sc.Dent. (Hons.)

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3. Abstract

The fundamental principle in any forensic investigation is based on the simple axiom, "any contact leaves a trace". The study of marks or artefacts left at the scene of a crime has always been an important means of proving or eliminating the presence of an offender. Bitemarks left on human tissue and bitten material have become an important aspect of the scientific evidence used for the conviction of a suspect. In the majority of cases, only qualitative evaluation of the bitemarks are involved. In these situations, the forensic dentist compares the morphological aspects of the offender's teeth with the bitemark present. The parameters used are features associated with the dental arch, such as the tooth morphology, position, number and distance between the teeth with those revealed by the marks. Even though bitemark analysis based on such comparisons is accepted widely by courts, the fundamental validity and scientific basis for its use as evidence has frequently been challenged. Expert opinion has often been based on associative comparisions rather than metrical analysis and many agree that there is a need to use additional comparative tests to achieve unbiased objectivity.

In this study, an interactive shape analysis program has been employed in an attempt to derive experimentally a quantitative comparison, in the form of a Similarity Index, between the "offender's" teeth and the bitemarks produced on a standard flat wax form. Similarity Index values obtained using the shape-fit program in ideal bitemark situations were evaluated and then these data were compared with those from studies of bitemarks produced on curved surfaces. Subsequently, the reliability of identifying bites in foodstuffs and on human skin, under experimental conditions, was assessed using the program.

The use of this Similarity Index is recommended as a simple, accurate and objective means of comparing bitemarks in forensic analyses.

B. INTRODUCTION

In medico-legal practice, teeth are known to be of great value in the identification of an individual. On account of this significance, a bite injury or a tooth mark has often been accepted as definite reliable evidence in a criminal investigation. In support of this Furness (1981) maintained that a criminal may "lie through his teeth" but the teeth themselves cannot lie.

Bitemark comparison therefore represents a vital area of expertise that dentistry has contributed to the forensic sciences. This technique involves comparison of the bitemark patterns present at the site of the crime with the alignment of the teeth and with other characteristics of the dentition of a suspect (Sopher, 1976). The use of imprints or marks made by the human dentition on skin or inanimate objects has been well accepted for identification purposes by the scientific, law enforcement and legal communities (Benson, Cottone, Bomberg & Sperber, 1988). Sognnaes (1977) held that bitemark patterns may be looked upon as somewhat comparable to an ante-mortem dental record, i.e. as a chart or mirror-image "cast" of a person's dentition. This over-optimistic view however, is not supported by most other forensic experts.

The shape of the marks on the skin does not, in fact, always correspond with the edges of the teeth (Korkhaus, 1955, as quoted by Harvey, 1976). Jakobsen and Keiser-Nielsen (1981) claimed that bitemarks in skin are never an exact reproduction of the offender's teeth and thus a mirror-image cannot be expected. Nonetheless, these authors stressed the importance of characteristic details when they are present. Strøm (1963) took a more cautious view and emphasized that it was easier to make a positive statement to eliminate a suspect rather than to prove the suspect's guilt.

The field of forensic odontology is established on one simple scientific axiom; just as no two people have the same fingerprints, nor will they have identical dentitions. The odds against identical dentitions occurring in the population have been estimated to be an impressive 2.5 billion to one (Berndt, 1982). Though twins may look alike superficially, it was found that even in uni-ovular or so-called "identical" twins, the incisal bites are not necessarily identical, i.e. not dentally identical (Sognnaes, Rawson, Gratt & Nguyen, 1982). In the time of William I (1027-87), green wax seals were used on State documents and the Conqueror introduced the simple technique of placing impressions of the royal teeth into the wax to indicate the authenticity of the seal and thus prevent falsification of important documents (Holt, 1980).

Bitemarks may be found on living or dead persons where that person may be the victim of a crime or even the perpetrator of the crime. Predatory animals leave bitemarks on their prey which can serve to indicate the species responsible for the attack. Bitemarks have also been reported in foodstuffs, flesh and in a miscellaneous group of materials, including bottle caps, cigars, cigarette holders, pipes, musical instrument mouthpieces, bullets and wooden cabinets (Furuhata & Yamamoto, 1967; Harvey, 1976).

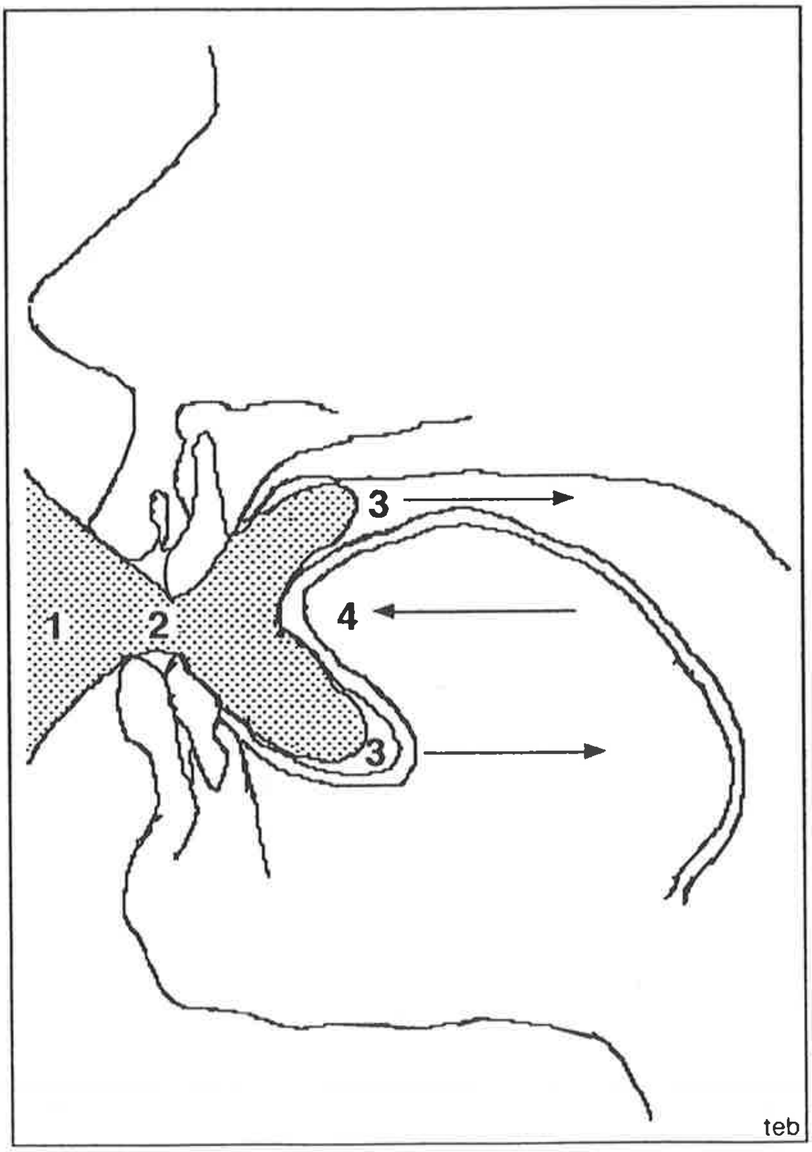
The analysis of bitemarks requires full scientific investigation where objective principles and scientific procedures are followed and should not be considered merely as a subjective comparison between the teeth of the perpetrator and the marks on the object. Bitemark evidence has led to the indictment, court trial and conviction of suspects in crimes associated with homicide, sexual assault, child abuse and other physical altercations. It can establish that the suspect was with the victim at about the time of a crime and that the suspect acted violently towards the victim (Vale, 1986). Assault victims in the pædiatric age group are classified under the battered child syndrome and may show a variety of injuries, including bitemarks. In some instances, the bitemark may be caused by the assailant forcing the hand or forearm of the victim into the victim's own mouth in order to stifle screams.

1. Notable bitemark cases.

Cameron and Sims (1973) stated that the first reported bitemark case was published by Skrzeczkas, a century earlier. Strøm (1963) believes that the first person to be credited for having published an analysis of a bitemark is Sorup in 1924. The method he developed was called "odontoscopy", by analogy with fingerprint identification which is termed "dactyloscopy". By this method, plaster casts of the teeth of the suspect are obtained, dried and varnished. The incisal edges and occlusal surfaces are coated with printer's ink. Upon this inked surface, a sheet of moistened paper is pressed and a print is transferred from it to transparent paper. This print is placed over a life-sized photograph of the bitemark and a comparison is made. In Japan, Oshikane conducted research on the identification of individuals by means of bite and tooth marks as early as as 1931 (cited by Furuhata & Yamamoto,1967).

Figure 1

Diagram showing forces exerted upon tissue during the infliction of a bite.



1 = skin, 2 = bite mark, 3 = suction, 4 = tongue thrust.

The first occasion on which bitemark evidence was presented as the main prosecution evidence for a crime of murder was in Scotland in 1968 but this case, unfortunately, has been the subject of a great deal of subsequent speculation as to the scientific accuracy of the evidence. This, the 'Biggar murder case' (Harvey, Butler, Furness, Laird & Brownlie, 1968), is perhaps the most famous bite case in British legal history and has set something of a precedent for the acceptance of bitemarks on skin in courts of law. This case was widely reported in various dental, legal, medical and forensic journals. Keith Simpson (1968), a renowned forensic pathologist, acknowledged this as a triumph for forensic odontology and described it as a "remarkable example of the penetrative value of sound, scientific evidence".

The year 1970 was the first time in the U.S. that bitemark evidence was accepted and in 1971 it was accepted for the first time in Canada. It is remarkable that the first apparent mention of the importance of bitemarks in a murder trial in America was in the trial of John R. Rice (Luntz, 1972) for the murders of his mother, sister, brother and grandmother in 1970. The teeth marks were the only piece of evidence that could connect young Rice directly to the killings.

It is evident that, nowadays, many civilian jurisdictions and military courts will admit crucial bitemarks as credible and persuasive evidence in determining the guilt or innocence of a suspect.

2. Bitemarks - some basic considerations.

Initially, it is important to decide what constitutes a bite mark and to attempt to define the term 'bitemark'. The Collins Dictionary definition of the verb *to bite,* is "to tear, cut or seize with the teeth". In a forensic sense, the term is used rather more broadly and it is suggested that a suitable definition of a bitemark is "a mark caused by the teeth either alone or in combination with other mouth parts" (Macdonald, 1974). This definition merely implies that the marks may not only be made by the teeth but also with a combined sucking and tongue thrusting force (sometimes termed 'suckling') (see Figure 1). It does not however attempt to indicate the nature of the material in which the mark was registered or the degree of force which caused the teeth to leave a mark.

To make a successful bitemark comparison, it is essential that only a short interval exists between the time of infliction and the analysis of the bitemark. Generally however, it is quite difficult to investigate bitemarks. Although no two dentitions are identical, bitemarks may on occasion appear similar because sufficient tooth characteristics have not registered in the impression of a bite. The human skin is a poor medium for bitemark registration. The appearance of bitemarks is influenced by both the mechanism and forces which produce them and by the mechanical properties of the skin and subcutaneous tissue or of other materials. Bitemarks also differ according to the particular way the bite was made (especially its direction) and the condition of the dental arch and teeth (indicating identifiable peculiarities) of the assailant.

The appearance of a bitemark on the skin will vary from site to site according to the mechanical properties of the tissues at each site. The tissues of the breast, for example, are innately softer than those of the back. In addition to these site variations, there are directional variations at given sites due to pre-existing tension lines (elastic fibres of the dermis) in the skin, known as Langer's lines. Flexion, extension and rotation of surface skin markings would be expected to follow the pattern of these lines (Barbenal & Evans, 1977). Other factors that influence appearance of bitemarks are the curvature of the surface bitten and 'dragging' during the biting process.

The actual biting of the victim is a dynamic process which involves complex movements of the jaws relative to each other, as well as the possible movement of the victim in defence. The geometric shape of individual imprints and the shape and size of the arch are characteristic of the assailant's dentition, provided there is no post-traumatic swelling or shrinkage of the bitten tissue or material. There will always be difficulties in the measurement and subsequent study of the marks in comparison with suspected dentitions, if any gross shrinkage or swelling has occurred. Clothing through which a bite is inflicted will tend to reduce the degree of force on the tissues and may be responsible for the absence of injuries from a particular tooth (Sopher, 1976).

Bitemarks usually involve the anterior dentition and may contain impressions of between five and twelve teeth (Duguid & McKay, 1981). In a case study by Levine (1973), maxillary and mandibular teeth were clearly defined in the bitemarks. According to Levine, the maxillary teeth are used for holding and they produced only slightly diffused marks, while the mandibular teeth are used for cutting and create more clearly defined marks.

The experimental re-creation of an incident by simulating the bitemarks produced is usually not feasible, especially when the biting force has to be very painful on the subject. This is because the 'offender' and 'victim' are not in a combative or life-threatening situation as would have pertained in an actual assault.

3. Classification of bitemarks.

a. The Cameron and Sims classification.

Cameron and Sims (1973) classified types of bitemarks into two groups; the agents that produced the marks and the materials or substances that exhibited marks.

(i) Agents producing bitemarks.

(a) Human:

It should always be remembered that bites on tongue, cheek, arms and legs may be self-inflicted, e.g. after a fall, a fight, during a sporting event, an epileptic seizure, under general anæsthesia or during local dental anæsthesia. Frequently, children are responsible for the biting of other children in boisterous play or by reason of aggression and jealousy. The arch size and individual tooth marks will indicate if the agent was a child or an adult.

Vale (1986) reported the importance of extra-oral examination of perpetrators to study factors that may influence biting dynamics. These include such as temporo-mandibular joint status, facial asymmetry, muscle tone and balance, maximal opening of the mouth, deviations in opening or closure and occlusal dis-harmonies. Facial scars or evidence of surgery should be noted. During intra-oral examination however, the size and the mobility of the tongue and also the condition of each individual tooth, especially the anteriors, should be carefully observed. According to Cleland (1944), teeth in a legal context are not categorised as weapons (i.e. objects to be used in fights). Any aggressive wounding caused by them, however, would indicate a criminal assault.

(b) Animal:

Cleland (1944) described bites from monkeys, camels, pigs, wombats, rats, crocodiles, scorpions, spiders and centipedes. It is important to distinguish animal bites from those caused by humans. Animals reveal bites with marks, tears and lacerations which vary according to the dental arch pattern of the particular species. Dog bites, perhaps the most common non-human bite, are characterized by a narrow anterior dental arch consisting of deep tooth wounds over a small area. The dog (or other carnivorous mammal) is also more apt to cause avulsion of tissue during violent biting. Feline bites are small and rounded with pointed cuspid tooth impressions, and claw scratches may be a particular feature with this species (Sopher, 1976).

"Bitemarks" reportedly produced by animals have been classified under the following loose headings:

Mammal	**Reptile**	**Fish**	**Bird**	**Insect**
Canine	Snake	Shark	Magpie	Bee
Feline	Lizard	Barracuda	Eagle	Wasp
Rodent	Crocodile	Piranha	Crow	Ant
Porcine	Alligator	Eel		Spider
Marine				

(Cameron & Sims, 1973; Cleland, 1944)

(ii) Materials exhibiting bitemarks.

(a) Foodstuffs:

Strøm (1963) and Gustafson (1966) report that it is often easier to analyse a bitemark in a foodstuff than in human tissue. This is evident as a bitemark on skin will become easily distorted because of the extension or flexion of the tissue.

Some foods will preserve clear marks of teeth and cases have been reported of convictions from bites in apple, chocolate, cucumber, roast pork (Webster, 1982) and cheese (Layton, 1969). Bitemarks have also been observed on oranges (bitten through the skin), persimmons, pears and potatoes. Bread is an unreliable matrix but buttered bread can leave clearer marks (Simon, Jordan & Pforte, 1974). Most biscuits are poor substrates, especially wafer types, but biscuits covered with fondant or chocolate are less liable to crumble. Due to their plasticity, butter and cheese are good materials for revealing the patterns of bitemarks (Layton, 1969). A sliding bite, which is observed in bites of butter or cheese will tend to reproduce more accurately the configuration, contour, width, curvature and peculiarities of the labial surfaces of the teeth than will shearing (e.g. apple) or piercing (e.g. skin) bites.

In 1933, Humble (cited by Whittaker, 1975) reported one of the earliest cases of bitemarks on food, where a burglar was convicted in 1906 from the marks of his teeth in cheese. A rapist was convicted in 1955 because of his teeth marks on a cucumber (Harvey, 1976) while the marks left on the pastry portion of a meat pie were instrumental in the conviction of a murderer (Furness,1971 as quoted by Cameron & Sims, 1973).

Furuhata and Yamamoto (1967) stated that chewing gum leaves a poor record of bitemarks but is suitable for saliva and blood group estimations. According to these authors, indentations found on the chewing gum failed to reveal the actual dental morphology of the biter. However, an offender in South Australia was convicted of burglary as a result of characteristic teethmarks left on a wad of chewing gum found at the scene of the crime (unpublished case report, Forensic Odontology Unit, Adelaide, 1990).

As an additional aid, it is recommended that clothing, marks and lesions should be viewed under UV lamp to display the faint fluorescence of saliva or any previous mark on the body which may be invisible to the naked eye (Cameron & Sims, 1973).

(b) The skin:

Human skin would seem to be a poor material for reproducing tooth imprints, due to its elastic properties and ability to move over the supporting tissues. Moreover, bitemark injury may present a diffuse bruise appearance rather than a well-defined pattern. It is evident that qualitative as well as quantitative evaluation must be considered in establishing the most important concordant points between bitemark lesions and the dentition of potential suspects. Details of the marks could reveal the position of the assailant at the time of the bite and perhaps the approximate time before death at which the bite was inflicted.

Some experts believe that evidence, which involves the identification of a person by tooth marks left as bruises in the skin, should never be admitted. Simpson disagrees entirely and Harvey (1976) quoted Simpson as stating that one of the best bitemarks he ever saw was the discrete and well-defined bruising produced in the breast of the deceased in the Gorringe case in Kent, England. The investigation and analysis of any bruise mark should never be delayed because the bruise pattern will spread and then the characteristics will become blurred.

b. Ætiological classification of bitemarks.

An "excellent" bitemark has been described by Macdonald (1974) as a recent mark, complete with tooth indentations (which favour a three dimensional study) capable of reproduction in an impression-making medium, definite areas of contusion, and the presence of specific peculiarities in the alignment or arrangement of the bitemark components.

Since bitemarks are frequently highly complex, it is pertinent to examine them from an ætiological view and to enquire how the changes observed in the bitten material have actually been produced. The classification of bitemarks proposed by Macdonald (1974) will be illustrated by marks in human flesh but it is equally applicable to marks in other materials.

(i) Tooth pressure marks:

Marks are caused by the direct application of the incisal edges of anterior teeth or the occlusal surfaces of posterior teeth upon tissue. The exact nature of the marks produced probably depends upon several factors; the 'sharpness' of the biting edge of teeth, the force applied, the duration of the application, and the degree of movement between tissue and teeth during the application of the force. In such marks, the incisor teeth leave pale areas representative of the main part of the incisal edge and a zone of bruising at the margins of the incisal edge. This is due to damage to blood vessels at the area of maximum stretching adjacent to the relatively static tissue that is actually in contact with the incisal edge of the tooth.

(ii) Tongue pressure marks:

When the material bitten can be taken into the mouth adequately and is sufficiently malleable, it may be pressed by the tongue against the teeth or other rigid areas of the mouth, such as the palatal rugae, and this can leave distinctive marks. In bites in flesh, this mechanism has been referred to as 'suckling' as it involves a combination of sucking and tongue thrusting (see Figure 1).

Marks produced by tongue pressure are usually imprints of the palatal surfaces of the upper anterior teeth but marks of the lingual surface of lower incisors may also be found. A series of arcs is seen which represents the outline of the palatal surface of the upper incisor teeth. These marks are caused by bruising due to stretching of supported tissues across the gaps between teeth or at the cervical margins during which time the main mass of the tissue is held relatively steady against the tooth surface or the gingiva.

The force developed by tongue pressure has been measured at between 8 and 10 lbs (3.6 to 4.5 kg) in men, 6 to 8lbs (2.7 to 3.6 kg) in women and 2 to 5 lbs (0.9 to 2.3 kg) in children. It was also observed that the force of the tongue thrust could actually exceed the suction pressure in many of the subjects (Kunvery, 1959, as quoted by Harvey, 1976).

(iii) Tooth scrape marks:

Such marks usually involve the anterior teeth and may present as scratches or as areas of superficial abrasion according to the width of the teeth producing them. If such marks occur as scratches, then they may be indicative of peculiarities in the incisal edges and this is of value in identification.

Bitemarks may be described as penetrating or non-penetrating according to whether or not the teeth penetrate through the epidermis. Consideration of such elements of the bitemark can give an indication of the probable circumstances in which the bite was made.

c. Holt's classification

In another classification scheme, which is independent of the substance bitten and the reason for the bite, Holt (1980) proposed three categories, teeth marks, arch marks and bitemarks.

(i) Teeth marks:

In the investigation of teeth marks of human origin on a body of a person, their position will help to determine the possibility of them being self-inflicted and from the detail of the marks one can often determine if the tooth making the mark had any morphological or acquired defect which would produce a mark of significance.

(ii) Arch marks:

The term "arch mark" in the dental context is taken to mean the pattern presented by the upper and/or lower teeth of the dental arch. In a bitemark, however, it is unusual for any teeth posterior to the first premolar to produce a mark. The inter-canine width will give some idea of the size of the mouth of the assailant and thus indicate the possibility of a child's bite or that of an adult with a small mouth. Jakobsen and Keiser-Nielsen (1981) supported the contention of Berg and Scheidt (1954, quoted by Whittaker, 1975) that 4 to 5 marks of adjacent teeth must be present before a mark can be identified as a human arch mark. This seems to be a subjective rather than a precise basis for a definition.

(iii) Bitemarks:

If it is an aggressive bite, the marks of the teeth and dental arches are usually multiple, in close proximity to each other, and often with the outer layer of the skin being penetrated or even torn. If it is a so-called "love bite" (an amorous or erotic bite), there is a combination of tongue thrust and sucking. These can cause an oval bruise mark within the arch area as the small blood vessels in the skin are ruptured in the biting action. In this type of bite, it is not uncommon to see a pattern of the upper front teeth as the tongue of the biter forces the tissue of the victim on to the teeth.

d. The Whittaker and Macdonald classification

Whittaker and Macdonald (1969) stated that bitemarks are often complex injuries and their recognition and interpretation depend upon a clear understanding of the mechanisms involved. They categorised bitemarks as follows:

(i) Definite bitemarks:

Each tooth has caused a mark because of direct application of pressure by its biting edges, thereby causing noticeable tissue damage. Other elements of the injury have however been caused by the suckling force.

(ii) Amorous (erotic) bitemarks:

Bites made in amorous circumstances tend to be made slowly with no movement between the teeth and the tissue. The marks of lower teeth are caused by gently increasing pressure into the tissues. By contrast, the marks of the upper teeth form a series of arcs where tissue was sucked into the mouth and pressed against the backs of the teeth with the tongue. The markings in the centre of the bite are caused by tongue pressure pushing tissue against the rugae of the roof of the mouth.

(iii) Aggressive bitemarks:

These bitemarks may be produced by a range of bite severities from moderate to very aggressive. The wounds cannot be positively identified as bitemarks and it is practically impossible to say which tooth would have caused the elements of the bite.

e. Webster's classification of bitemarks in foodstuffs

Examination by Webster (1981) of the mechanism of biting and of bites thus produced has shown three main types of bitemarks in food:

(i) Type 1:

Those found in material such as chocolate, which fractures readily after a limited depth of tooth penetration. Bites of this type will record the most prominent incisal edges of the upper and lower anterior teeth, up to a depth of 1 to 2 mm.

(ii) Type 2:

Those where a good grip of the material is obtained by the teeth and then the bitten piece is removed by fracturing it from the main material. This is typical of bites seen in firm fruit such as apples, pears and in large pieces of cheese. Both the upper and lower labial outline marks and the tooth scrape marks tend to record those elements of the teeth which are prominent anteriorly.

(iii) Type 3:

Teeth bites through, or almost through, the bitten material, a feature which is typical of the bitemarks found in cheese. The morphology of the bitemark exhibits extensive scrape marks and may give an indication of the relative position of the upper and lower incisor teeth in centric occlusion.

4. Sites and incidence of bitemarks in human skin.

Human bites are a serious medical and surgical problem. A wide range of secondary consequences have been documented in the medical literature, which include deformity, amputation, infection, transmission of disease agents, and psychosexual aberrations (Marr, Beck & Lugo, 1979). By comparison, the much feared dog bite produces a relatively uncontaminated wound in the half million or so annual victims in the United States. The possibility of rabies account for greater fear of the dog bite but human bites have a much greater potential for producing necrotizing deep infection (Brandt, 1969) and also the spread of AIDS, hepatitis B, venereal disease and other infectious diseases.

Since the earliest report of a human bite case in the medical literature by Burnett in 1898, numerous authors have described their successes and failures in the clinical treatment of human bites. Marr *et al* (1979) reported an incidence of 11.8 human bites per 100,000 of the general population. They found that the extremities were the location for 61.2% of the bites and that 55.4% of these involved the hands superficially (including thumb and fingers).

It is necessary to distinguish epidermal lesions or injuries which could be mistaken for possible bitemarks. Examples of those that mimic bite injuries are fixed drug eruptions, sub-acute cutaneous *lupus erythema*, *pityriasis rosea*, *tinea corporis* and *granuloma annulare* (Gold, Roenigk, Smith & Pierce, 1989). Sometimes, lines or marks from such toothed articles as chain saws, combs, and gear wheels must be differentiated from bitemarks.

Spiers (1941) reported 114 cases in Kansas, of which 27 bites were on fingers, 14 on the knuckles, 2 on the palm,18 on the arm, 2 on the shoulder, 4 on the forehead, 12 on the lip, 4 on the nose, 13 on the cheek, 5 on the ear, 7 on the breast, 2 on abdomen, one on the back and 3 on the thigh.

In another study by Rawson, Koot, Martin, Jackson, Novosel, Richardson and Bender (1984), 1100 children were examined during the three-month period from 31st March to 28th June, 1982, and, of these, 17 showed evidence of bitemark abuse. This represents an incidence of 1,545 per 100,000 sheltered children or about 1.5%. A comparison of the location of bitemarks reveals that 14.9% of the bites reported in the Marr *et al* (1979) study occurred on the head and neck region, whereas 42.9% of the bites in the Rawson *et al* study occurred in this area.

Cases in which children are the victims of human bitemarks are not uncommon. Schweich and Fleisher (1985) reported an incidence rate of one human bite in every 600 visits to a pædiatric emergency room. This is slightly lower than the 1-2% incidence reported in adults. Annually, there are approximately 25,000,000 children seeking treatment in Emergency Departments (E.D.) of hospitals in the U.S.A.. Assuming the above data are representative of the general population of treated children, the authors estimated approximately 41,000 E.D. encounters annually because of human bites in children. They found that 30.3% of the bites occurred on the face, whereas 18.2% were on the hands. In 88% of the cases, the children were bitten by other children. It was also observed that many adult human bites which occurred on the hands are caused when one adult strikes another on the teeth.

Baker and Moore (1987) studied human bites in children and teenagers and recorded 322 human bites occurring over a six-year period. The majority occurred during warm weather months between 2 pm and 11 pm. They found an incidence of one bite in 615 E.D. visits with 42.6% occurring in upper extremities, 32.6% on the face and neck and 21.8% on the trunk. In this series, 61.5% were the result of fight injuries, 25.8% occurred while they were playing, 7.1% during love-making, 4.7% during sport activity and 0.9% as a result of abuse. Most bites (75.2%) were superficial abrasions, 13% were punctures and 11% were lacerations.

In an independent study of 67 bitemark cases, Vale (1986) found that 42 of the victims were women and only 25 were men. For the women, many of whom were victims of sexual assault, the highest proportion of cases involved bitemarks on the breast, arms and legs. Among male victims, the bitemarks were most frequently found on the arms and shoulders. This is in agreement with studies conducted by Rawson *et al* (1981) and Marr *et al* (1979) who found an increased number of bitemarks on pre-teen and teenaged females.

Although many of these clinical studies indicate that it is the upper extremities (particularly the hand and fingers) that are most commonly bitten, information from the forensic science literature shows that a completely different spectrum may be encountered by forensic analysts. From a total of 74 bitemarks studied by Furness, Simpson and Harvey (1976), it was found that "most bites occurred on the breast". Specifically, 23 bites occurred on the breast, 12 on the face or head and 10 on the hand or arm. These indicate that a considerable proportion of bites seem to be associated with erotic behaviour.

Vale and Noguchi (1983) however, found that the occurrence of bitemarks in forensic cases were indeed consistent with the clinical incidence. The highest number of cases (37.3%) involved bitemarks on the arms. If hand and fingers were also included, bitemarks were found on the upper extremities in nearly twice as many cases (43.3%) as on the breast (22.4%). It is estimated that 65% of all bites are found in areas easily viewed without having the patient disrobe (Rawson, 1986).

Levine (1982) identified certain areas where bitemarks occurred frequently during sexual encounters. He tabulated his findings as follows;

Non - sexual assault	**Sexual assault**			
	Heterosexual victim		**Homosexual victim**	
	Female	Male	Female	Male
Extremities Thorax Chest	Breast Thigh Shoulder, anterior Pubic area Neck Arm Buttocks	Abdomen Chest Arm	No cases reported	Upper back Axilla Shoulder, posterior Penis Scrotum Breast Arm

He reported that bitemarks may be found anywhere on a child who had been a victim of assault by adults or other children but a significant number of these bites were to be found on the cheek of the victim.

5. Determining the age of a bitemark injury.

Forensic experts often have difficulty in determining the age of a human bite injury is when a victim presents for examination. This difficulty is due to the variability of the tissue involved, the depth of the bite and the type of injury, all of which affect the normal healing process. Bacteria in the wound will also hinder normal healing by enlarging the wound and competing for the vital nutrients, such as oxygen and glucose, needed for wound healing. This causes tissue anoxia, the production of lactic acid and further breakdown of the wound. Bite age can best be approximated using histological and biochemical determinations (Gold, Roenigk, Smith & Pierce, 1989). The accuracy of such analyses is greatly assisted by an understanding of the mechanisms of wound healing.

The immediate result of bruising may not be obvious or may show merely as a red blush. The discolouration will be more marked after the passage of time and it is therefore always advisable to re-examine the bruises 24 hours later as the initial appearance of slight swelling or tenderness which may indicate a struggle or restraint will, by then, have manifested as obvious bruises.

Generally, the shape and degree of bruising is related to the causative agent and amount of violence but this relationship must be interpreted with caution since certain factors will modify the effect;

a. Conditions and type of tissue. If the skin is loose or has excessive subcutaneous fat, bruising will occur more easily and be more extensive. Conversely, if the skin is strongly supported by fibrous tissue, then bruising will be considerably less or even absent.

b. Age. Infants and old people tend to bruise easily. The former do so because of the delicacy of the skin, while the latter have poorly supported blood vessels due to the loss of subcutaneous fat.

c. Sex. Women have a tendency to bruise more easily than men because of the relative delicacy of the skin.

d. Texture and colour of the skin. Fair-skinned persons reveal bruises more than persons with more pigmented skins.

e. Organic disease. Persons suffering from scurvy, purpura, hypertension and degenerative cardiovascular changes tend to produce more extensive extravasations of blood and, as absorption of the extravasated blood is slower, the colour changes may be delayed and histologically characteristic.

The age of a bruise can be roughly estimated from its colour. Immediately after infliction it will be reddish, turning soon to a dusky purple or black. After 4 to 5 days, there is a green discolouration and this changes to yellow in 7 to 10 days, the bruise usually disappearing in 14 to 15 days. These colour changes take place from the periphery, and the overall time period involved may vary from 1 to 4 weeks (Cameron, 1976).

To decide whether any injury took place just before, at the time of, or just after, death is a difficult matter. A true ante-mortem bruise inflicted a short time before death will usually show swelling and infiltration of the tissues with blood. It must be noted that post-mortem changes may confuse the issue but antemortem injuries produced several hours or days before death will show obvious macroscopic and microscopic tissue inflammatory reaction. For this reason, tissue samples showing these lesions should always be retained in a fixative solution.

When a lesion occurs at an appreciable time after death, bruising will be absent and tiny abrasions may take on a characteristic brown appearance. With respect to postmortem changes, the mere passage of time does not negate the validity of a bitemark comparison. Many defence counsel will make an issue of post-mortem shrinkage of tissue as a ploy for discrediting the forensic analysis. A body which does not manifest the more obvious effects of post-mortem decomposition will display minimal, if any, distortion of the bitemark during the time since infliction. Any detectable changes would represent a lesser source of dimensional error than possible change related to distortion of the skin surface as a result of the pressures inherent in the act of biting (Sopher, 1976).

The tissue response to a wound can be divided into three stages, inflammation, granulation tissue formation, and matrix formation with remodelling. The inflammatory stage consists of a series of vascular events, along with platelet activation, to re-establish hæmostasis. This is followed by the migration of various components of the immune response (including neutrophils, monocytes and their tissue products, macrophages) to assist in the breakdown of necrotic dêbris and to help remove bacteria from the wound area. The granulation tissue formation stage of wound healing is divided into a proliferative phase, which is characterized by epidermal regeneration with an influx of fibroblasts into the wound, and a fibroblastic phase, beginning 4 to 5 days after the injury and characterized by the synthesis of a large amount of collagen. Wound contraction is an important feature of this stage. The final stage, which is matrix formation and re-modelling, begins simultaneously with granulation tissue formation and is characterized by the organization of the collagen bundles into a scar.

Reasonable estimates of wound age can be determined from human bites, for instance, laceration wounds that have not yet re-established hæmostasis would be classified as being in the early stages of inflammation and thus would be only several hours old. Erythematous lesions are also part of the inflammation stage and, depending on the degree of erythema, could range in age from several hours to 7 to10 days old. Laceration injuries without erythema would be considered in the granulation tissue formation or matrix formation/remodelling stages and would be older than 10 days (Gold, Roenigk, Steven, Smith & Pierce, 1989).

Tissue changes from bitemarks have been tested in volunteers whose skin has been submitted to histological study. The most obvious vascular damage was found in the deeper dermal regions, where the larger blood vessels are located. Even after the œdematous reaction had regressed, a considerable number of erythrocytes remained in the dermal region, which explained the distinctive erythematous discolouration of the skin. (Millington, 1974). This type of examination can be of great value in supplying supportive evidence in the assessment of both time of application, extent and intensity of a bite injury. The evidence itself is not substantive but could be useful correlative data in the investigation of such cases.

6. Experimental comparison of bitemarks.

Few studies have been carried out to determine the reliability of comparison techniques of bitemarks in food or skin. Fernhead in 1961 (quoted by Whittaker,

1975) carried out experiments on bitemarks in various foods and commented on the changes occurring in the hours following the bite. Even under ideal laboratory conditions, it was not possible to be certain which dentition was responsible for the bites and the author stressed the need for a more critical awareness of the problem.

In another experiment (Rawson, Vale, Sperber, Herschaft & Yfantis, 1986), a large dog was anæsthesized, hair was removed from the legs, back and abdomen and bitemarks produced on the shaved areas with eight sets of dental casts mounted on simple hinge articulators. Photographs of bitemarks were then sent with the eight sets of unidentified models to seven forensic odontologists for determination of the proper matches. Only one investigator was able to match all eight sets of models correctly to the bitemarks that were produced. The average reliability, or accuracy in correctly matching bitemarks to the dentition, was 66%. This investigation however, was small in scale and has attracted some criticism since no standard investigative procedure was employed by the experts.

Whittaker and colleagues (1975) found that experimental bites into pigskin, taken from recently-killed young animals and wrapped around a rubber cylinder, could be matched with only 70% accuracy even when assessed immediately after biting. One hour later, the accuracy of identifying the 'potential offender' by this pigskin test was reduced to about 35%. This was further reduced to 16% after 24 hours of refrigeration, the specimen being warmed to ambient temperature before this final examination. These comparisons were made with photographs of the bitemarks taken at the appropriate intervals of time.

Yano (1973) included phantom models for comparative bite model studies. These were hard rubber rollers, 50 mm in diameter with 'skin-like' surfaces of vulcanized rubber of about 1.5 mm thick. Experimental bites on the models were then compared with bites on forearm skin of volunteers. It was found that the resulting bites depended not only on the position and alignment of the teeth but also on secondary movements during the action of biting.

This was supported by a clinical case study by Sognnaes and Therrall (1975). In this incident, an 18-month-old girl was tumbling with her father on the lawn. The child suddenly fell on to her father in such a way that the child's upper front teeth penetrated the skin of the father's forehead about 9 cm below the hairline. Two clearly visible lesions were characterized by an arrangement which produced a V-shaped pattern with a distance between the two, suggesting slightly unaligned incisors with a diastema at the midline. The angle (120°) formed by the marks proved to be slightly more acute in the skin lesions of the father's forehead than that from experimental bitemarks made with the tooth model of the child (140°).

It was concluded that, in the creation of the accidental bitemark in the skin, the teeth appeared to have caused the puncture wounds not merely by a major vertical impact but one potentially compounded by minor horizontal and rotating movements. These latter could be due to either the movement of victim's body or perpetrator's head during infliction or both.

It must be emphasised here that no two bitemark cases are alike and experts will carry out the investigation using whatever available means they feel are applicable to the particular circumstances (Furness, 1968).

7. Recognition and interpretation of bitemarks.

The principle objective of bitemark investigation is to ascertain whether one is dealing with a bitemark and secondly whether the bitemark is human or animal in origin (Dorion, 1982). Bitemark analysis involves both quantitative and qualitative evaluation of the injury. The qualititative analysis involves the concept of specificity and uniqueness of the bitemark and involves the search for peculiarities of the bitemark which may then be compared to the suspect's dentition for the same characteristics.

a. Subjective assessment.

The case history is obtained from the investigating officer and the testimonies of the victim and witness are thoroughly evaluated. These may help the investigations in that the objective findings may be corroborated or possibly negated.

b. Objective evaluation: an outline of recommended procedures.

(i) At the scene of the crime, determine if victim is alive or dead.

(ii) On clinical examination, determine the pattern and proximity of the two arches (ovoid or elliptical, if it is a human bitemark). Determine if there is any possibility of re-creation of the position and condition of the victim/material and perpetrator of the crime and also rule out the possibility of self-infliction.

(iii) Determine if the bitemarks are single or multiple and, if the victim is deceased, whether they occurred before or after death. Estimate the probable age of the injury and determine if it could have occurred with any other associated crime.

(iv) Consider whether the psychological status of the assailant can be deduced from the type of injury.

(v) Determine blood groupings, the presence or absence of saliva, oral flora, tooth fragments and suction marks (probably found only in human bites).

(vi) Estimate the width and form of the semi-circular arches (from tooth alignment); width and form of individual marks (teeth); the opening diameter (distance between the upper and lower central incisors); the position of the central line; the distance between the canines and depth of penetration of individual teeth. Ascertain the arch which holds and the arch which incises. This is possible by recognition of the incisor injury pattern, where disparate widths will sufficiently indicate whether one is examining upper or lower jaw.

(vii) Selectivity of tissue bitten may be an indication of the type of attack (e.g. sexual assault).

It must be emphasised here that various other intrinsic and extrinsic factors affect a bitemark lesion, during or after its production. The intrinsic factors that can affect bitemarks are the general health and medical condition of the victim, age, sex, physical constitution, melanin pigmentation of the skin, tissue tone and tension lines. The extrinsic factors that can affect bitemark evidence are the presence of other physical deformations near the bitemark (tyre marks, stab wounds, etc.) Furthermore, exposure to influences such as temperature, humidity, soil conditions (e.g. sand, soil bacteria) and to salt or fresh water, chemicals, fixatives, embalming fluid and other contaminants, will affect the bitemark.

Biting through the clothing will leave a distorted pattern of a bitemark with possibly insufficient detail on the skin. There may, however, be a registration of the bite on the cloth.

Some of the above factors also can affect bitemarks in foodstuffs. The age of the foodstuff when first examined, the size (weight and volume) and the type and consistency of the material (solid or semi-solid) are other factors that also should be considered.

8. Recording and preservation of bitemarks.

There is a need for rapid action by forensic odontologists in recording and preserving of bitemarks. Changes occur rapidly in the appearance of bitemarks, both those in human tissue and in foodstuffs, because of the effect of elapsed time. Bitten foodstuffs deteriorate over time, thereby obliterating the bitemarks produced on them. Bitemarks inflicted on human skin are especially transient in nature and therefore preservation of the evidence is mandatory.

a. Bitemarks on human skin

In the event that the bitten person is alive, evaluation of the marks is made extremely difficult by changes in their appearance. Among these changes are possible infection, swelling and discolouration of the area from bruising, abrasion or laceration of the tissues. These might obscure the bitemark but the use of an ultraviolet lamp may make the marks visible again (Dinkel & Captain, 1973).

In a deceased person, the tension of the skin lasts for some hours after death and, during this period, the marks are relatively sharp. When this tautness departs , the bitemarks are less easily seen and may be 'smoothed out'. In addition, the effect of putrefaction, which may occur 48 to 72 hours after death, will also influence changes in the shape and appearance of the bitemark. Shrinkage of the corpse due to the loss of water will have an effect on the appearance of the bitemark. Some forensic odontologists recommend excising the area of the skin containing the bitemark for the purpose of preservation and subsequent evaluation. In the case of a bitemark produced in the breast of a deceased female, it is recommended that the whole breast be removed.

Strøm (1963) also recommends transection of the arm or leg to include a broad margin on both sides of the bitemark present. Upon removal of the bitten tissue, the specimen should be preserved in 10% formalin (formaldehyde solution) or Keiserling's solution. A tissue shrinkage of 10 to 20% is inevitable with such preservatives, thereby obviating any future comparative measurements since the mark is no longer a life-sized specimen (Dinkel & Captain, 1973). Strøm (1963) criticised the removal of only the skin flap for examination as it can exhibit a shrinkage of almost two-thirds, in spite of the immediate fixing of the skin flap in formalin.

b. Bitemarks in foodstuffs

Edible material that has been bitten should be examined as soon as possible. Just as human tissue will alter its shape, so will edible material as time progresses. The early deterioration that can occur in foodstuffs is due primarily to the drying of the material, particularly in those with a high water content.

The forensic usefulness of edible material depends upon the consistency of the bitten material, the manner in which the bite is applied and the amount of deterioration that has transpired prior to its processing. Bites that occur in hard cheese, hard butter, fruit (particularly apples), and hard sausage can provide excellent marks.

Once the juices of an apple have evaporated, any marks left by teeth will become extremely distorted, or even obliterated. Apples shrivel, turn brown and decompose with time. Cowley (1954) used a commercial fruit- preserving tablet (containing 50% available sulphur dioxide) which, when diluted in a half-pint of water, completely preserved the apple core when it had been immersed in the liquid and sealed for two months. It appeared that no gross swelling or shrinkage had taken place with only general discoloration occurring. Hodson (1970) proposed that fruit can be preserved without distortion if placed in a solution of formalin, acetic acid and alcohol (5ml of 40% formalin, 5ml of glacial acetic acid and 90ml of 70% ethyl alcohol). The use of this methodology is supported by Rudland (1982), who also found that the most successful preserving fluid for botanical specimens was formalin-acetic acid-alcohol mixture.

Marshall, Potter and Harvey (1974) however, demonstrated that the dimensional stability of different varieties of apple was dependent upon the preserving fluid and that no single preserving solution was likely to be suitable for all types of apple.

Cheese, chocolate, meat and baked foods can be preserved by refrigeration in 'air-tight' plastic bags until examination is possible (Stoddart,1973). Extreme care must be taken in the handling of all edible material, as the bitemark itself is fragile and could easily be damaged inadvertently.

c. Saliva sampling.

The majority (approximately 85%) of the population secrete blood group antigen in body fluids such as perspiration, tears and saliva. It is possible, therefore, to determine the biter's blood type from traces of saliva. The identification of saliva is particularly important, for the concentration of the blood-grouping antigen is four times as high in saliva as in normal human blood cells.

Saliva swabs should be taken from bitemarks, both those in human tissue and those in edible material. The sampling technique utilizes a cotton swab moistened in saline and sampling is started at the outer portions of the bite and worked inward with a circular motion. After each swab is used, it should be placed in a labelled, stoppered glass container and a 'chain of custody' for the sample must be initiated.

Clift and Lamont (1974) recommend the collection of saliva using 1 sq. cm piece of "Rizla"-type cigarette paper held in forceps and dampened with fresh tap or distilled water before swabbing. In addition to a swab of the bitten surface, a control swab used in a similar fashion should be applied to an unbitten area of the skin surface of the victim. The intra-oral saliva and a blood sample of the victim must also be procured for examination purposes (Sopher, 1976). These samples are then sent to a forensic serologist for examination. If no definite results are obtained, it may be due to one of the following reasons:

(i) the perpetrator was a 'non-secretor'
(ii) no saliva was left on the area (i.e. probably not a bitemark).
(iii) saliva trace evidence was removed by prior procedures

d. Photography.

Photographing the bitemark is a very important step in the processing and registering of bitemarks. The bitemark should be photographed with both black and white and colour film. Black and white film allows for finer resolution upon printing or enlargement. The colour photographs can be used for the detailed comparison and show to advantage the gradation of pressure points and areas of bruising and abrasion. The photographic recording of the actual three-dimensional relationship of a bite is almost impossible unless carried out (with considerable difficulty) by the use of a special stereoscopic camera.

Ideally, while the photographs and impression of the bitemarks are being taken, attempts should be made to arrange that the victim adopts the exact position in which the bite was inflicted. This is important because skin is elastic and any other position assumed by the victim may alter the shape of a bitemark (Dinkel & Captain, 1973).

Two close-up shots of the bitemark should be taken at the 'correct' exposure, and then followed with two additional close-ups; one at one half stop less and the other at one half stop more. Using the last two settings compensates for under-exposure or over-exposure if there was a slight mis-calculation initially and, at the same time, affords the chance to detect other evidence that might not be apparent to the eye (Luntz & Luntz, 1973). An accurate scale of size should be included in the photographs so that actual dimensions of the bitemark can be measured. The scale should be positioned to ensure that it does not obscure the evidence and yet is in the same plane of the bitemark.

In cases in which bitemarks are on a curved surface, it is extremely difficult to depict the exact distance between individual teeth marks by means of a single photograph. For this reason, separate photographs should be taken of the different areas of the bitemark, for example, the upper and lower arch mark on each side of the injuiry. It should be remembered, however, that a photograph provides a flat representation of a three-dimensional object and marks on skin are usually on curved or angular surfaces. The camera must, therefore, be orientated for successive photographs to be taken over the curved surface with the principal object plane parallel to the film plane and at right angles to the long axis of the lens assembly of the camera (Cameron & Sims, 1973).

When the bitemark indentations are shallow, the best results can be obtained if the light source falls obliquely upon the surface. Oblique lighting using a single floodlight or flash is useful in bringing out texture and subtle surface indentations of the mark. For optimal results, the film plane should be parallel to the plane of the bitten surface and the plane of the scale. There are three primary factors that require attention in positioning the camera relative to the bitemark and the scale;

(i) the required portion of the bitemark and the scale should be well within the field of view of the camera.
(ii) the film plane should be closely parallel with the plane of the scale.
(iii) the camera should be firmly mounted to avoid camera movement during exposure.

Parallelism between the scale and film plane is accomplished by placing a small mirror in the plane of the scale, then moving the camera until the reflected image of the camera lens is centred in the focussing screen. The mirror is removed before the shutter is triggered.

Hyzer and Krauss (1988) introduced a rigid L-shaped scale (unfortunately made from unplasticised PVC, which is not the most dimensionally stable of plastics) with three printed reference circles which allow for detection and correction of errors in parallelism between the object and film planes, thereby permitting more accurate appraisals of bitemark arch forms. It also provides assistance in photographic quantification of bitemarks, evidence collecting techniques and analytical procedures.

This technique has certain shortcomings which have been noted by Ebert (1988). He emphasised that bitemarks are seldom found on a flat surface and therefore the idea of placing the scale "nearest" to the lesion with the use of clip and arm jig is not possible and only an approximation is feasible. Furthermore, quite sophisticated equipment is required for correcting the film plane during processing of the photographs. Ironically, this manœuvre actually compounds the distortion.

Photographs should be taken at intervals of 24 hours to record the changing nature of any bruising and also the healing process of a bitemark, especially when the initial swelling has subsided.

e. Impression-making for the registration of bitemarks

One of the best methods of preserving bite mark evidence is to make an impression of the indentations and subsequently to prepare a three-dimensional model of the bitten area. The value of the impression method rests upon the fact that bitemark indentations of the skin can be reproduced exactly in a stable three-dimensional model and thus the dimensions of depth and shape are provided for comparison. Skin surface hair is carefully clipped prior to impression-taking rather than shaving the area, since the latter may result in scab material being removed. Some experts recommend that, when taking impressions, the bitten area should be in the same position as that when the injury occurred (Levine, 1977).

The important requirements for an impression material capable of accurately reproducing bitemarks are that it should;

(i) flow easily and be capable of producing the finest detail.
(ii) be quick-setting at room temperature.
(iii) be durable and dimensionally stable.
(iv) have a high viscosity that can be regulated to give a variation in setting time.
(v) have high cohesion, firmness and elasticity.
(vi) have no detrimental influence on tissues or material through chemical or thermal action.
(vii) be readily available.

f. Materials available for impression making.

(i) Elastomeric impression materials are currently the most popular for impression-making since they provide excellent detail, elasticity and dimensional stability. The elastic recovery of the these materials ranges from 97.9 to 99.5% when a model is made within the manufacturer's time specification. They are classified into four groups: polysulphides, polyethers, condensation (conventional) silicones, and addition silicones (vinylpolysiloxanes).

Polysulphides and polyethers exhibit the greatest distortion of (0.6%) at 24 hours after polymerisation. Vinyl polysiloxanes (e.g. "Exaflex") appear to be the most stable with only 0.05% distortion at 24 hours, making this class of impression material the first choice for forensic science purposes. As a result of the flexible nature of impression materials, a more rigid external backing or internal reinforcement is required to stabilize the impression during removal and subsequent handling. Plaster of Paris and dental stone have been recommended by some for this purpose. Methyl methacrylate, an auto-curing acrylic material has been advocated as a conventional and rigid backing material (Benson, Cottone, Sperber & Bomberg, 1988).

Souviron, Mittleman and Valor (1982) used gauze mesh reinforced with dental stone for the rigid backing. Sometimes, the impression material is reinforced with semi-rigid thermoplastic orthopædic tape (e.g. "Hexcelite"). The orthopædic tape is cut to the approximate size of the bitten area and warmed in hot water rendering it plastic and placed over the impression material, the tape becoming rigid upon cooling.

A variety of other semi-rigid materials are also available for providing such a backing support for the impression. One good example is "Optosil Plus" (Bayer Dental). This is a silicone-based, kneadable impression material which is dispensed as two mixing components, liquid and paste.

It is important that information regarding the date of examination, location of bitemark, victim's name or case number and initials of the person making the impression must
be recorded on the impression backing. The orientation of the bitemark with regard to other body structures should also be included on the impression, usually marked with arrows and also index marks on the skin. This information is subsequently recorded by taking a photograph. If there is any evidence of air bubbles on the impression, the impression should be retaken.

(ii) The usefulness of Plaster of Paris as an impression medium is limited by its inability to record fine detail or to be removed from undercut surfaces. The heat generated during setting may also be uncomfortable to the living subject and produce surface changes due to provocation of the inflammatory process.

(iii) Reversible hydro-colloid (agar) and irreversible hydro-colloid (alginate) have also been used but are not desirable due to their susceptibility to dehydration and subsequent distortion of impressions if stored for any length of time, i.e. if positive models are not made immediately from these impressions.

(iv) Ligthelm and We (1983) examined the applicability and accuracy of an auto-polymerising "BIS-GMA" resin when used as an impression material for forensic purposes. According to these authors, the relatively long polymerization time (8 to 10 minutes) of all elastic impression materials is a disadvantage when used with live subjects and a more rapidly-setting agent is highly desirable. They observed that impressions can be made with careful use of light-curing filled BIS-GMA resin, while chemically-curing BIS-GMA resin (polymerisation within 3 minutes) can be used with success on non-vital tissue. Caution is emphasised here as there is a possibility of histological damage to vital tissues.

9. The expert witness.

Strøm (1963) stressed the need for bitemark cases to be examined primarily by dentists who have made a special study of the subject and have gained practical training with a colleague experienced in this area. Sopher (1976) even suggested that a forensic pathologist is not qualified to handle bitemark analysis. Dentists however have received specialized training in the development and relationship of the jaws, anatomy and arrangement of the teeth and also in handling impression materials. Furthermore, the courts must be satisfied that the expert witness is truly knowledgable and qualified to analyse the bitemark injury.

10. The admissibility of bitemark evidence.

Historically, the admissibility of any type of scientific evidence has been traditionally problematic. The perceived inability of law-enforcing officers to assess adequately the scientific expert testimony has led to the development of particular rules governing the admissibilty of scientific evidence.

One American legal test for determining the admissibility of scientific evidence was introduced in 1923 in Frye *v.* United States (Sognnaes,1976).

The court stated in this case as follows:

> *"Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognised and, while courts will go a long way in admitting expert testimony deduced from a well-recognised scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs."*

Beckstead, Rawson and Giles (1979) re-affirmed that the technique on which a testimony is based must be generally accepted as being reliable and had been performed by adequate and accepted procedural techniques, as acceptable in the scientific field to which the technique belongs. It is generally held that the admissibility of scientific evidence requires that it be based on certain accepted procedures within the scientific discipline.

Reliability or relevance of evidence depends on three factors; the validity of the underlying theoretical principles, the correct utilization of scientific technique and the drawing of the pertinent conclusion by a properly qualified expert (Hales, 1978). Only relevant evidence is admissible in courts and this requirement is only satisfied if the evidence offered has any tendency in reason to prove or disprove any disputed fact that is of consequence to the determination of the action.

Briefly, the identification process of a bitemark involves three stages; the gathering of data about the bitemark, comparison with the relevant data of the suspect and, finally, the evaluation of the significance of similiarities or dis-similarities revealed by that comparison. Since the logical process of recognition, registration, comparison, interpretation and final conclusion by a forensic dentist upholds all the above scientific principles in bitemark investigation, it has been recognised as a relevant and credible body of evidence acceptable in courts. Berndt (1982) even stressed the additional need for "artful persuasion" of juries, to enhance the credibility of this kind of scientific evidence, together with the use effective presentation procedures.

The increased acceptance by the courts of the admissibility of bitemark evidence has required suspects in a bitemark case to submit to dental examination for purposes of a bitemark comparison. Nevertheless, in some countries, a potential legal problem may confront the investigating agency in its efforts to gain access to the dentition of a suspect. In his defence, the suspect may object to such an examination on the grounds that dental photographs, dental impressions and saliva swabs represent techniques which may serve as evidence against him or as intrusion of his privacy (Sopher, 1976).

For example, in the U.S.A., the suspect's counsel may invoke objection against the examination by claiming refuge under the protection of the Fourth or Fifth Amendments to the American Constitution. Respectively, these amendments state that an individual has a right to be free of unreasonable searches and seizures and that a subject has a privilege not to incriminate himself. It is advisable to obtain a legal consent form signed by the suspect, or by the legal guardian in the case of a minor, giving permission for the examination and taking of photographs or impressions or alternatively obtaining a court order for the same purposes. Dinkel (1974), however, has stated that he could not find a single recorded instance in which the constitutionality of compelling a suspect to submit to the taking of a dental impression had been litigated.

Levine (1982) stated that bitemark evidence apparently has been admitted at the trial court level in each case where it was offered and in no known instance has an appellate court ruled that the admission of bitemark evidence was reversible error. Berndt (1982), however, did report that in one case, People *v.* Milone (1973) in DuPage County, Illinois, the suspect had been wrongly convicted of murder, primarily on bitemark evidence. This has caused some hesitation by prosecutors in using bitemark evidence in the U.S.A.

In South Australia, a suspected person charged for a bitemark offence is required to submit to the taking of the impression of his teeth under Section 81, Subsection (4)(b) of the Summary Offences Act,1953, as amended in 1985. Refusal to comply constitutes an offence with the person being liable to a penalty not exceeding $1000 or imprisonment for 3 months.

Admission of bitemark evidence also heightens the possibility of undue prejudice to the defendent. Bitemark evidence can be more persuasive to the ultimate issue of guilt than other analogous forms of evidence. Even fingerprints tend to be viewed as more circumstantial or associative (Hales, 1978). Therefore, if we accept the wisdom of the legal expression "proof beyond reasonable doubt", the investigating forensic dentist must strive to alleviate any problems of subjectivity associated with bitemark evidence and base his objective findings solely on sound scientific principles.

11. Interpretation and conclusions of the examiner.

Marks should be placed in one of three categories; definite bitemarks, possible bitemarks, and those marks which show features which specifically preclude them from being caused by the teeth (Macdonald, 1974).

Once a bitemark is confirmed, the problem of identification of the assailant must be addressed. When a suspect has subsequently been discovered, the following tests should be applied;

a. can the suspect be excluded from consideration as having produced the bitemark?

b. if the suspect cannot be excluded, how specific are the points of comparison which lead to the conclusion that the suspect alone could have produced the bitemark?

The investigator is confronted with the problem of determining the individuality of the bite characteristics and, more specifically, the problem of specificity of the mark for the suspect alone, i.e. to the exclusion of all other individuals (Sopher, 1976). Strøm (1963) recommends either a complete positive identification or a complete elimination. If the teeth of the suspect only tally to a certain degree, he does not approve a qualified positive statement given in terms of probability. If any inconsistencies can be established, then the subject must be immediately eliminated as a suspect.

Clearly, the development of a quantitative method of comparison with appropriate statistical confidence limits would be of great value for better acceptance of bitemark comparison evidence in courts.

C. METHODOLOGY AND DISCUSSION OF TECHNIQUES.

Forensic dentists usually interpret a bite wound qualitatively by associative comparison, where similarities or dissimilarities with the dentition that are claimed to have produced it are compared with the bitemark. It is inevitable that this kind of evidence will introduce a subjective bias and provoke questions in the courtroom regarding the reliability of the comparison. In recent years, mathematical techniques employing complex computer programs to determine general recognition, quantification and comparison of analogous shapes have received much attention. A method of forensic identification utilizing such computer technology for shape analysis would seem to be very desirable. When there is a high degree of correlation between the teeth and the bite pattern, it will be possible to determine the match to a particular individual.

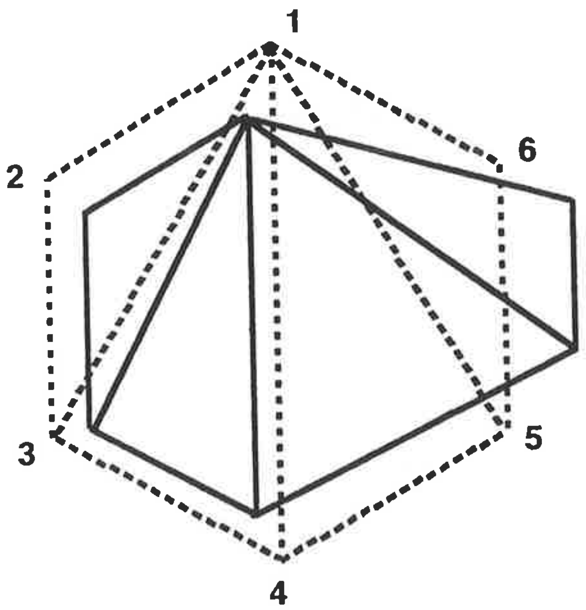
Accurate bite impressions can be produced on soft wax material or modelling clay ("Plasticine") and these materials are favoured for reproduction of the dentition. In an experiment by Whittaker (1975), two examiners were able to match subjectively 98.8% of the impressions in wax to a dental cast of the subjects and the same degree of accuracy was achieved when matching dental stone models produced from the wax bites against the dental casts of the subjects involved. Incorrect matching was found in only one case in which the incisal edges of the anterior teeth had not registered in the wax bite. Comparing photographs of wax bites with photographs of study casts of the subjects' dentitions, an accuracy of 96.0% was achieved by one examiner and 95.5% by the other. When photographs were used for visual comparison and no measurements taken, the accuracy fell to 68% for one examiner and 67% for the other. It is evident from the experiment that visual matching using subjective criteria was found to be less accurate than when measurements were also taken.

In the present study, an interactive graphics computer program was employed in an attempt to experimentally derive a quantitative comparison between a subject's teeth and the bitemarks produced on a flat sheet of a standard wax material. Values obtained using the 'shape-fit' program were then evaluated, such that statistical limits of individuals can be determined from bitemarks produced under optimum conditions. Subsequently, values obtained from these data were then compared with those from studies of bitemarks made on curved surfaces. The reliability of using this program in identifying bites on the skin and foodstuffs in experimental situations was investigated and analysed.

Figure 2a and b

Diagrams illustrating the different 'fits' that are achieved with the "least squares' method compared with the "robust" method (for explanation, see text).

a. Least squares method.



b. Robust method.

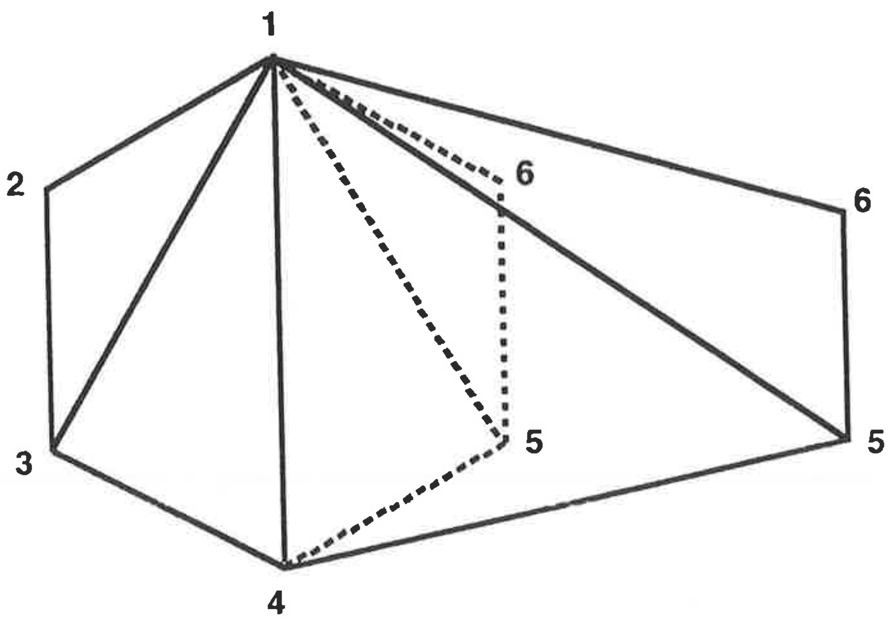
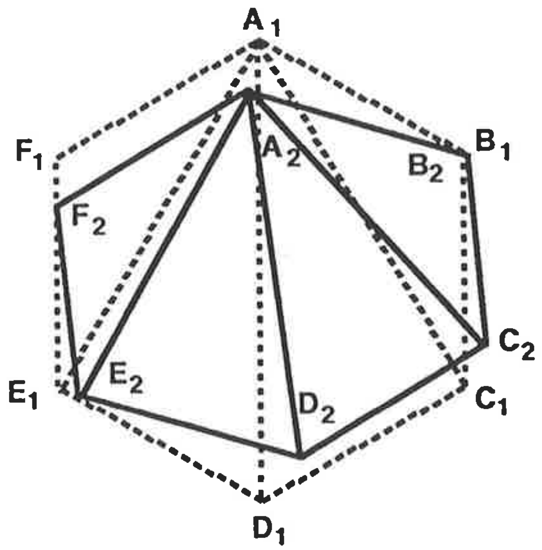


Figure 2c

The use of residuals to derive two indices of similarity with the least squares method of shape comparison (for explanation, see text).



Residuals.

Residual length (R) = distance between homologous points of shapes 1 and 2 , e.g. A_1, A_2.

Average residual length =

$$\frac{\sum R}{N} = \text{Similarity Index (S.I.)}$$

Root mean square = $\sqrt{\frac{R^2}{N}}$

Figure 2d Example of a computer printout from a comparison of two shapes using the shape analysis computer program applying the "least squares" algorithm. In this study, all values were corrected to two decimal places for data collection and subsequent processing.

S.I. = Similarity Index = Average residual length

Coordinates: x	y	Residual length (mm)

```
** LEAST SQUARES FIT **          B:6PP48.OUT
RESIDUALS: COORDINATES AND LENGTHS

   0.08070   0.46787   0.47477
  -0.18279  -1.13293   1.14758
  -0.23787  -0.14053   0.27628
   0.01443  -0.17406   0.17466
   0.15895   0.00636   0.15908
   0.20605  -0.23795   0.31477
   0.51742   0.05425   0.52025
  -0.30733   0.09897   0.32287
   0.22522   0.58600   0.62779
   0.51584   0.40313   0.65468
   0.40645   0.63547   0.75433
  -0.28259   1.12886   1.16369
  -0.03589   0.53964   0.54083
   0.34174   0.34401   0.48490
   0.19962   0.32166   0.37856
   0.21318  -0.03284   0.21569
   0.22359   0.47973   0.52927
  -0.38483  -0.27636   0.47378
  -0.15089  -0.12067   0.19321
  -0.27066  -0.30989   0.41145
  -0.47028   0.25697   0.53591
  -0.20044  -0.53185   0.56837
  -0.17331  -0.01367   0.17385
   0.14687  -0.02563   0.14909
   0.46143  -0.21724   0.51000
  -0.10704  -0.46314   0.47535
  -0.33621  -0.25395   0.42134
  -0.51662   0.13408   0.53374
   0.07578   0.29777   0.30726
  -0.54619  -0.75613   0.93277
   0.25462   0.20676   0.32799
  -0.28111  -0.39364   0.48371
   0.38635  -0.66348   0.76777
   0.05580  -0.21798   0.22501
AVERAGE RESIDUAL LENGTH =     0.47737 = S.I.
R.M.S.  RESIDUAL LENGTH =     0.53907

PARAMETERS A, B, C, D, RHO, THETA (IN DEGREES)

  83.94307 -30.09974   1.00000   0.08383   1.00351   4.7918
```

1. The interactive graphics program for shape analysis.

This computer program is used in identifying and measuring the location and extent of relative deformation of two shapes. It was adapted from a Fortran shape analysis program originally written by Siegel (1982) which has the facility for shape analysis by two methods, the "least squares" and "robust" methods (Figures 2a and 2b).

The robust method (Figure 2b) is useful in the detection of any localized shape differences when these are present. It will demonstrate close fit in similar regions but not close in relatively deformed regions. In our preliminary assessments for this project, it was not possible to get more than half the analogous points to match by the robust method. Therefore, it did not prove to be a useful technique in this research project.

The least squares method (Figure 2a) is used to find the common location and orientation of two shapes in order to compare their similiarities and differences. The method relies on the matching of co-ordinates obtained from sets of analogous points selected to best describe the shapes under study. The degree of matching is an expression of the similarity between two shapes.

In this study, it was preferred to employ the least squares method as it produces an overall fit, the residual value of which is a useful single number measure of the degree of difference between two specimens. The program also allowed two methods of estimating least squares fit but it was decided to employ "average residual length" rather than "root mean square residual length" because the values obtained with the former were comparatively lower (Figure 2c and 2d). Average residual length is obtained when the sum of the distance between homologous points of shape 1 and shape 2 is divided by the number of points.

In this thesis, the "average residual length" value is used as the numerical indicator of similarity between two shapes (see Figure 2d) and has been termed the Similarity Index (S.I.).

2. Production of experimental wax bites.

Bites were experimentally produced on three types of wax; "Coprwax", "Modelling Wax" and "Moyco Wax" (Figure 3). Although the exact composition of these waxes is

Figure 3 The materials used in this project to record experimental bitemarks

a. Surgident "Coprwax" Bite Wafers
b. Investo "Dental Modelling Wax"
c. Moyco "Beauty Pink-X-Hard Dental Wax"

a trade secret, they usually contain paraffin wax, beeswax, carnauba wax, candella wax, wool fat, gum dammar, stearine, oils and fillers. When wax is warmed with hot tap water (approximate temperature, 70°C) and manipulated, the wax becomes pliable.

Bites were made in such a way that impressions of the incisal edges of the upper and lower incisors, cuspal penetration of canines, premolars and molars were recorded. Each subject was instructed to bite a flat wax specimen in centric occlusion (i.e. biting with the mandible in the most retruded position). This was considered to produce relatively good teeth marks with a standardised biting procedure. A double thickness of wax sheet was employed for registering the flat wax bites whereas a single sheet was used to record bites on curved surfaces. Aluminium kitchen foil was placed in between the two layers of the wax to provide added strength and the sandwich trimmed to the dental arch profile (Figure 4). Under illumination, the exposed shiny surface of the foil clearly revealed the penetration of the incisors and the cusps of the posterior teeth.

Dental waxes (see Figure 3) tested in this study were;

a. Surgident "Coprwax" (Columbus Dental, St. Louis) was preferred by the Japanese investigators, Furukawa (1984) and Takei, Innami, Tsutsumi, Tsunoda, Furukawa, Komuro, Mukoyama, Takahashi, andYokosawa (1987). It produced satisfactory photographs because of thebrown (copper) colour. This wax, which is impregnated with copper powder, provides uniform heat transmission during the warming and cooling process. It is supplied in the form of precut "bite wafers" containing a sheet of aluminium foil to increase strength, aid heat conduction, prevent the teeth from cutting through and to reduce distortion. It softens easiin warm water (52 to 57°C) and so, after the bite is registered, it should be immediately chilled with cold water (19 to 24°C). Unfortunately, these wafers were found to distort easily because of insufficient width and their use in this experiment was discontinued.

b. Investo "Dental Modelling Wax" (The Investo Manufacturing Company,New South Wales) is supplied as sheets (160 mm x 80 mm with a thickness of 1.25 mm). It could not be satisfactorily bitten as uniform warming was not possible (melting point 55-60°C). Even with the application of fibre optic spot lights ("Volpi" Intralux 6000, Wild-Leitz Co., Switzerland), this translucent red wax did not permit the easy determination of the indentation marks (especially on photographs).

Figure 4 Bitemarks produced on a flat sheet of Investo "Dental Modelling Wax".

Figure 5a The model used for producing experimental bites on a curved surface (for details, see text).

Figure 5b End view of curved surface model to show the layers of different materials used in its construction.

c. Moyco "Beauty Pink-X-Hard Dental Wax" (Moyco Industries Inc., Philadelphia) was then assessed. Dental surgeons refer to this wax colloquially as "Beauty Wax". It is supplied as sheets of 14.5 mm x 7.3 mm with a thickness of 1.5 mm. It gave good identifiable incisal and cuspal marks, sufficient to make clear indications of each tooth indentation. This material could easily be warmed for uniform softness, the melting temperature being approximately 66°C. The uniformity of softening may have been due to the (undisclosed) presence of fillers used in the wax formulation.

It was decided to use the Moyco Dental Wax for all our subsequent studies since we found it superior to "Coprwax" and "Modelling Wax" particularly in the important areas of ease of manipulation and quality of photographic prints (see Figure 4).

Each flat wax bite was immediately photographed alongside a scale, using standardised lighting conditions, and models were poured in dental stone (Investo "Yellowstone-Hard"). Each model (positive) was given a separate code from the original cast of the the dentition of the subjects. To ensure that there is sufficient base material for the model, the wax bite was encircled with a cardboard "wall" before pouring the liquid dental stone mix. To obtain bubble-free models, the wax bites were initially cleansed with "Jelenko" wax pattern cleaner (Penwalt Jelenko, Dental Health Products, Armonk, New York, U.S.A). This is a wetting agent which reduces surface tension and removes any oil remnants on the wax pattern. Subsequently, stone mix was then poured on the wax bites and mechanically vibrated to remove air bubbles prior to setting.

For production of wax bites on curved surfaces, the Moyco Dental Wax was wrapped around a form made from EVA (polyethylene vinyl acetate) foam (10 mm thick), which encircled a piece of PVC (polyvinyl chloride) tubing measuring 100 mm long (Figures 5a and 5b). The diameter of the plastic tubing is 30 mm and with the encircling EVA foam, the diameter was increased to 50 mm. The EVA foam was attached to the underlying PVC tubing with double-sided adhesive tape positioned away from the biting surface and secured with elastic bands.

The EVA foam provided a soft underlay to simulate the consistency of human dermal tissue. Subjects were requested to bite slowly into the wax surface in order to make a clear indentation of the upper and lower arches.

Figure 6 Upper and lower casts of the dentition of a subject.

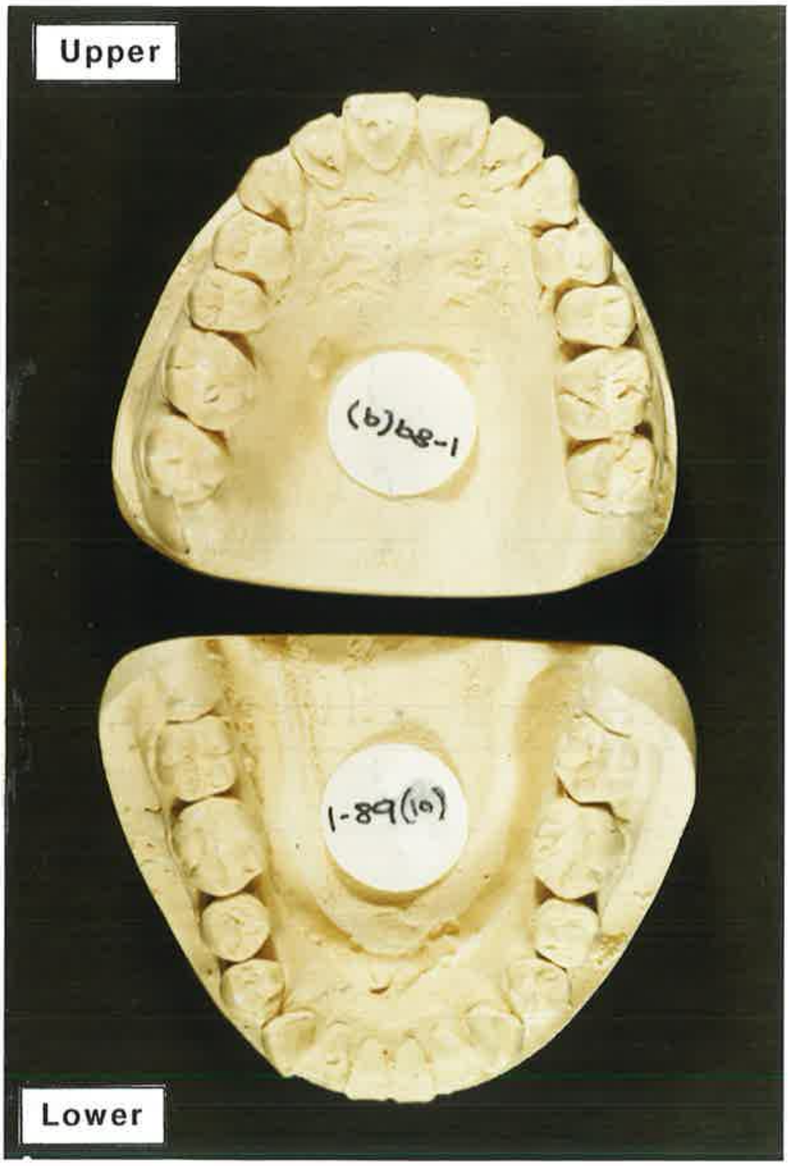


Figure 7a Customised stand for mounting camera and dental casts (for details, see text)

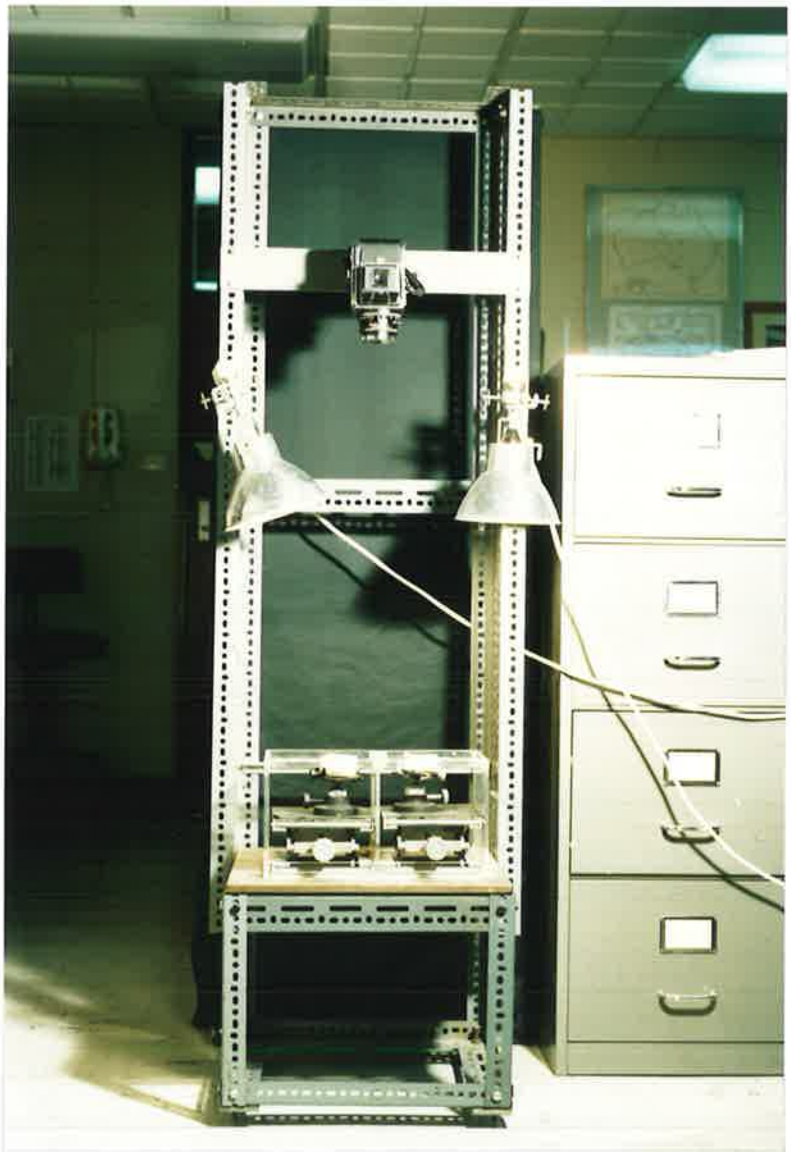


Figure 7b Laboratory jacks and Ney surveyor platform with dental casts in place (for details, see text).

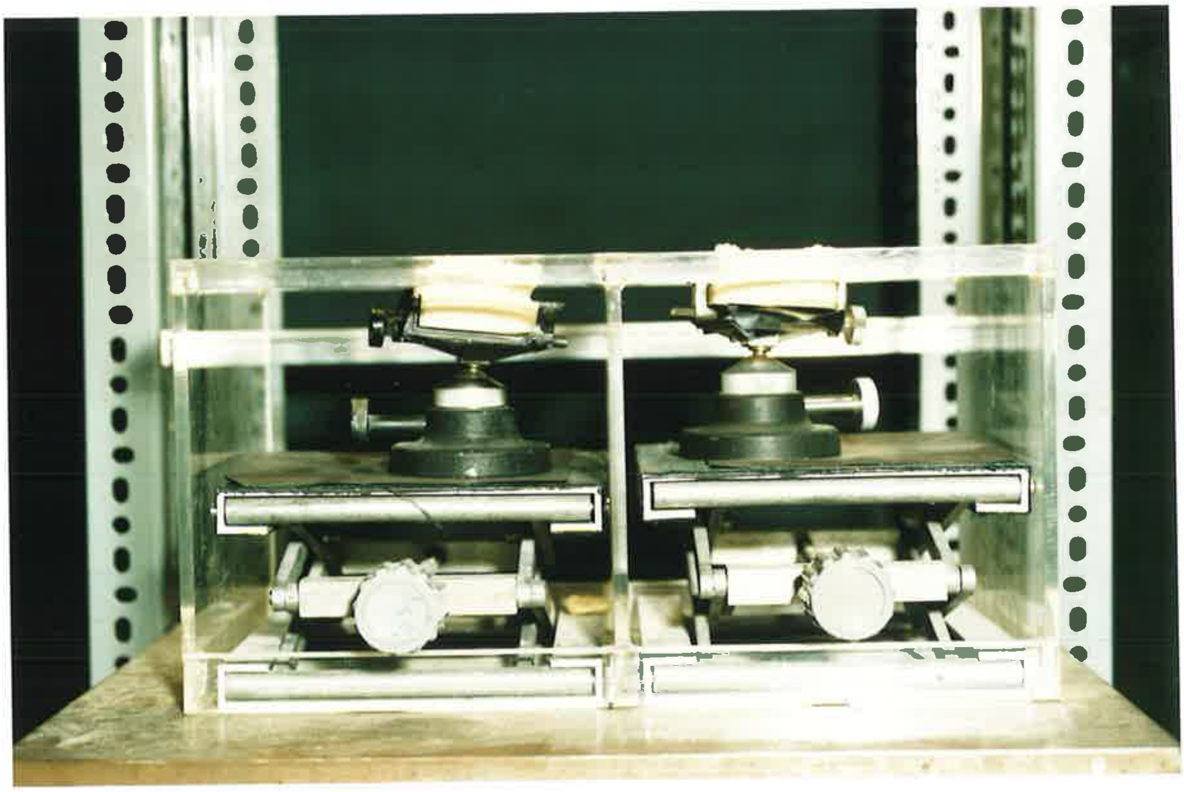


Figure 8 The levelling device placed on a dental cast (for details, see text).

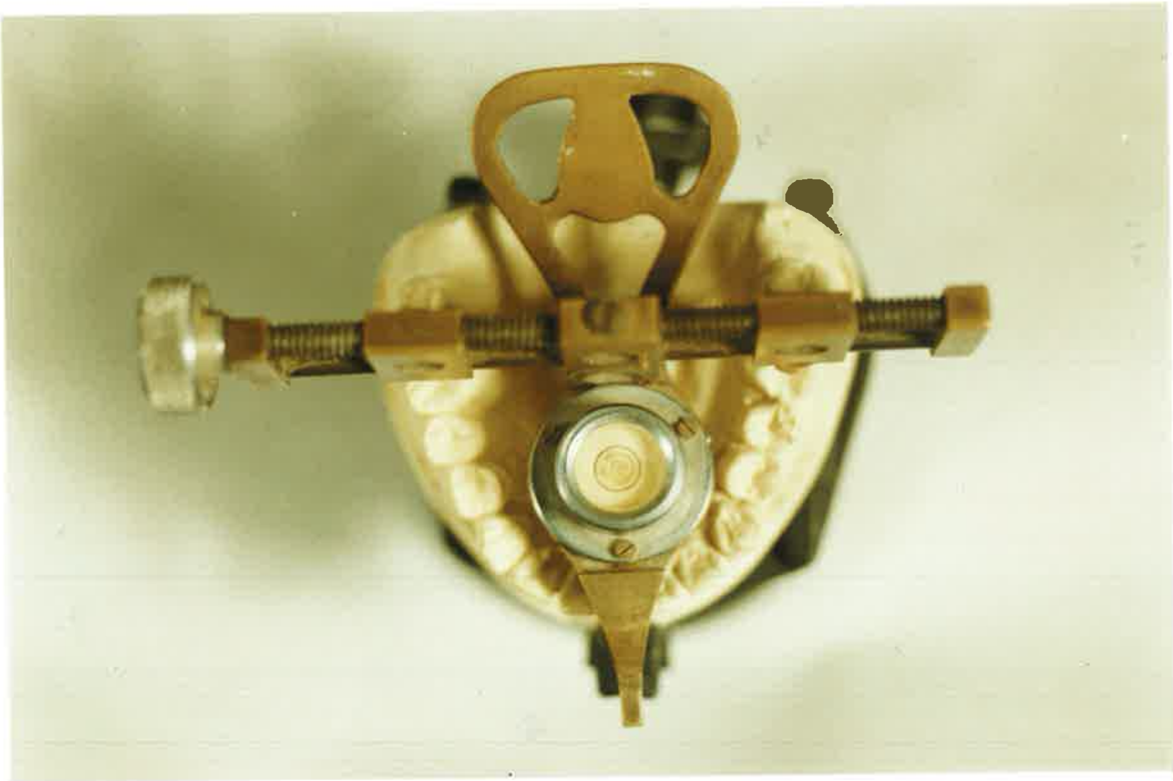
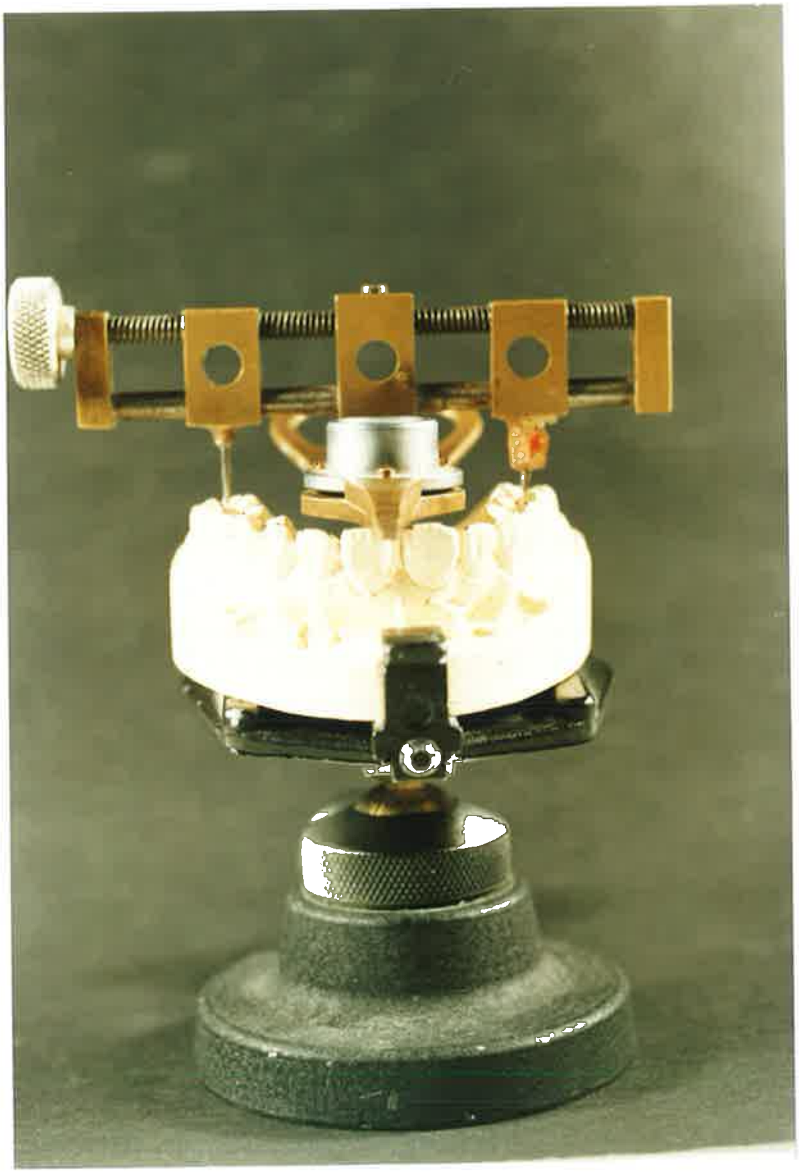


Figure 9 A dental cast mounted on a Ney surveyor platform with dental casts in place (for details, see text).



3. Photographic procedures.

The departmental collection of dental stone casts of the dentition of 46 subjects (first year B.D.S. students) was made available. These subjects represented several different racial groups, namely, Asian, European, Australian and Melanesian. For this research, casts (see Figure 6) of eleven subjects were selected randomly. These subjects (six males and five females) were then employed to produce "test bites". Four from this group were selected to perform "test bites" on foodstuffs.

Photographs of the casts were taken under 'ideal' standard conditions with a single-lens reflex Hasselblad "500EL/M" camera, fitted with an 80 mm lens and a "Proxar-F=1m" lens extension. This camera was set vertically in a fixed plane and was attached to a rigid rack, fixed by means of a locking device. (Figure 7a). The base of the rack was a flat, metallic table perpendicular to the camera and set about 390 mm. above the floor level. On this table, two laboratory jacks were placed, within a rectangular box-like framework (Figure 7b). The centre top portion of this rectangular framework carried a horizontal metric scale. As standardized lighting procedures were employed, all photographs were taken using the same exposure values (aperture size f11; shutter speed 1/30 sec.; exposure value 13) with oblique lighting. Lighting was provided by two adjustable photographic floodlights fitted with 150 watt incandescent globes.

Parallelism between the scale and film plane was accomplished by placing a mirror in the plane of the scale, then adjusting the camera until the reflected image of the camera lens was centred without distortion in the focussing screen.

The casts were orientated on the Ney surveyor table with a levelling tripod (Figure 8). The two points of the tripod were located in the central fossae of first molars with the arm resting on the incisor teeth (Figure 9). The surveyor table was connected to the base by a ball and socket joint facilitating ample rotation. Levelling was achieved by aligning a bubble in the centre of a circle inscribed on the spirit level built into the tripod. This was to render parallel the plane of the incisal tip of the incisors and the central pits of the first molars. If either or both first molars were absent, the tripod points were placed on the second molars. This plane was then positioned in the same level as the scale measurement, by adjusting the laboratory jack. The camera lens-scale distance was measured to be 72.5 cm.

Photographic reproduction of the wax bite illuminated by floodlights was not sufficient to reveal the marks on the prints, especially to discriminate each cuspal indentation individually. Improved lighting with the use of Volpi "Intralux 6000" fibre optic spotlights solved this problem. The bitten wax was placed on a black velvet cloth, kept parallel to the measurement scale, with spotlights focussed on the indentations and the specimen was then photographed.

Photographs were taken on 120 mm film format (Kodak "TMax400") suitable for the Hasselblad camera. Kodak "TMax" developer was used to process the film, after which it was fixed with Ilford "Hypan Rapid" fixer.
Printing was done on Ilford "Multigrade" paper using the 2·5 Ilford "Multigrade" filter on a LPL "Model C7700" colour enlarger. The photographic prints were enlarged to life size using the scale measurements and processing was done using Iford reagents.

4. Selection of reference points.

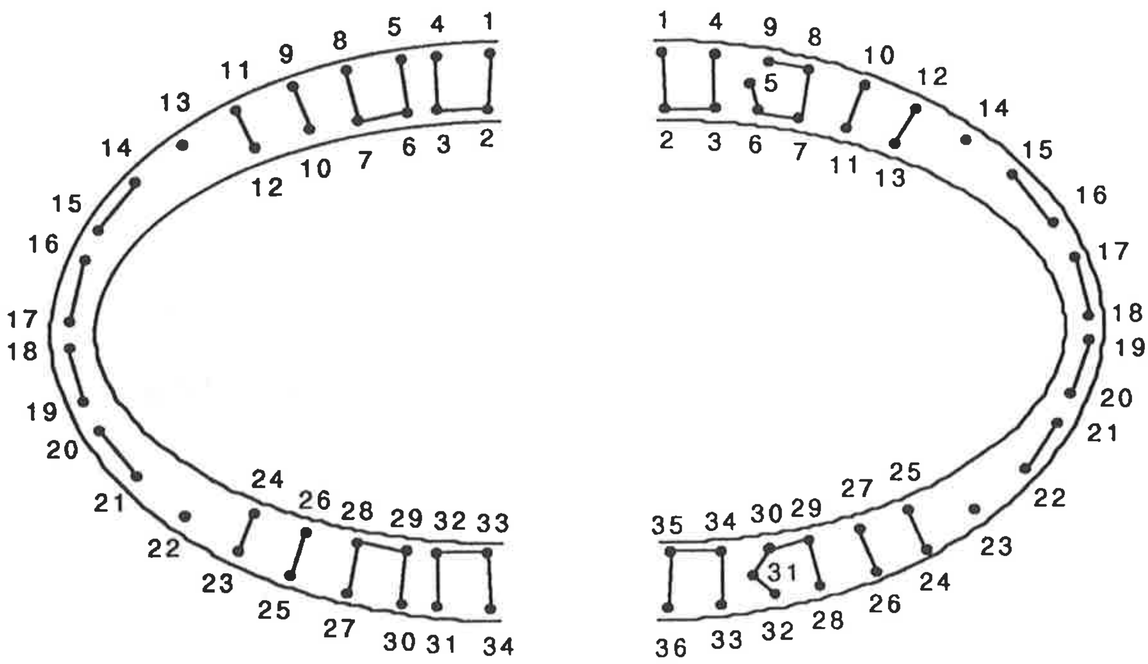
It is obvious that incisal and cuspal tips are involved in the actual initial penetration during a bite. The mesio- and disto-incisal angles were chosen as reference points for the incisor teeth, with cuspal tips for the canines. For the posterior molar and premolar teeth, cuspal tips were chosen as reference points. These points also provide an indication of the sizes of the teeth involved and also the shape of individual arches. In situations where the cusp tips were not present (e.g. due to attrition) or were restored, the centre of the cusp surface was used as reference points. Missing points due to anatomical anomalies, fracture or extraction of the teeth were recorded as "missing".

In an actual bitemark, it is the anterior teeth which are usually impressed into the 'bitten' material. In this study, however, the posterior teeth (except the third molars) were included in the bite analysis, since a greater number of selected points will increase the accuracy of a match and give a potentially lower numerical value for greater discrimination.

Figure 10

Diagram showing the sequence used when digitising reference points marked on photographs taken of dental casts, bitemarks or impressions of bite marks (for explanation, see text).

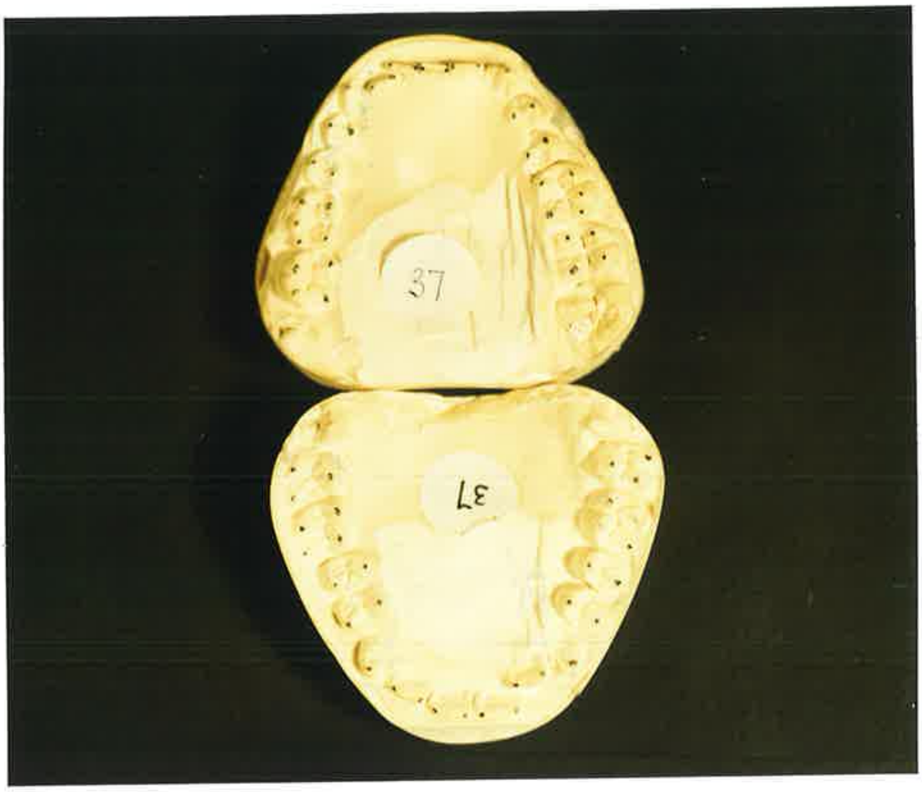
Upper jaw | Lower jaw



34 reference points | 36 reference points

Figure 11 An overlay of a bitemark digitised using the Calcomp digitiser (for details, see text).

Figure 12 Reference points marked on dental casts (for details, see text).



In total, 34 reference points of discrimination in the upper arch and 36 in the lower were employed (see Figure 10). These were:

<u>Upper arch (U)</u>

2nd. molar	- 4 points
1st. molar	- 4 points
2nd. premolar	- 2 points
1st. premolar	- 2 points
Canine	- 1 point
Lateral incisor	- 2 points
Central incisor	- 2 points

<u>Lower arch (L)</u>

2nd molar	- 5 points
1st molar	- 4 points
2nd premolar	- 2 points
1st premolar	- 2 points
Canine	- 1 point
Lateral incisor	- 2 points
Central incisor	- 2 points

5. The digitising of reference points.

All casts, wax bites and positives from these wax bites were photographed under standard conditions. Digitising was performed on an overlay upon which the reference points had been marked by tracing over the photographic prints. Each dental arch was described by co-ordinates of the reference points located within a Cartesian system of orthogonal x and y axes. The reference points in both upper and lower arches were marked on all teeth except the third molars.

Direct digitising from photographic prints was avoided as the conductance of the silver compounds on the latter might affect the accuracy of digitising on the platen. Digitising (Figure 11) was performed on a Calcomp 2300 digitizer (Calcomp Digitizer Products Division, Anaheim, California, U.S.A.) connected to "Laser 386 SX" (IBM-compatible) computer (Logi-Tech, Adelaide, Australia).

Table 1 Reference table of the comparisons which have been made (*) in this study between casts, bite impressions and positives of bite impressions, within single subjects ('self'). The results of the actual comparisons are given in Tables 2 to 7 and the overall results are summarised in Table 8.

SUBJECT CODE	CAST OF DENTITION		BITE IMPRESSION	POSITIVE OF BITE IMPRESSION	
	Cast photographed and points marked on overlay.	Points marked on cast. Photographs taken and points traced on overlay.	Flat wax bite photographed and the points marked on overlay.	Positives photographed and points marked on overlay.	Points marked on positives and photographs taken. Points then traced on overlay.
B-S	*	*	*	*	*
J-Y	*		*	*	
K-U	*		*	*	
L-K	*	*	*	*	*
H-S	*		*	*	
C-N	*		*	*	
W-U	*		*	*	
Z-L	*	*	*	*	*
S-K	*	*	*	*	*
R-I	*	*	*	*	*
A-D	*		*		
COLUMN	**A**	**B**	**C**	**D**	**E**

Table 2 Comparison of Column C with Column A (see Table 1)

'Self' comparison of the flat wax bite with the subject's dental cast. Photographs of each were taken and reference points marked on an overlay placed on the photograph.

SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	1.140	0.814
J-Y	0.816	0.689
K-U	1.048	0.728
L-K	0.975	1.966
H-S	1.048	1.104
C-N	1.669	0.818
W-U	1.133	0.861
Z-L	0.875	0.761
S-K	1.372	0.876
R-I	0.696	1.123
A-D	0.880	1.579
Mean: ± SEM n	**1.059** ± 0.082 11	**1.029** ± 0.121 11

Table 3 Comparison of Column D with Column A (see Table 1)

Self comparison of the positive with the individual's dental cast. Photographs of the cast and of the positive of the bitemark were taken and reference points marked on overlays placed on the photographs.

SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	0.661	0.582
J-Y	0.604	0.734
K-U	0.860	0.862
L-K	0.668	1.550
H-S	1.304	0.775
C-N	0.828	1.787
W-U	0.869	0.725
Z-L	1.016	1.382
S-K	0.682	1.095
R-I	1.308	0.718
Mean: ± SEM n	**0.880** ± 0.081 10	**1.021** ± 0.131 10

Table 4 Comparison of Column C with Column B (see Table 1)

Self comparison of flat wax bite with the individual's dental cast. Points marked on the cast, photographs taken and the points traced on an overlay.		
SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	1.367	1.588
L-K	1.246	2.716
Z-L	0.824	2.301
S-K	1.148	0.774
R-I	0.680	1.056
Mean: ± SEM n	**1.053** ± 0.130 5	**1.687** ± 0.366 5

Table 5 Comparison of Column E with Column A (see Table 1)

Self comparison of the positive with the individual's dental cast. In this situation points were marked on the positive, photographed and points traced on an overlay and matched with the cast photographed and points marked on an overlay.		
SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	1.934	0.836
L-K	0.741	0.690
Z-L	0.948	0.984
S-K	0.859	2.356
R-I	0.595	2.043
Mean: ± SEM n	**1.015** ± 0.237 5	**1.382** ± 0.341 5

Table 6 Comparison of Column D with Column B (see Table 1)

Self comparison of positive with the individual's dental cast. In this situation, the positive was photographed and points marked on an overlay and compared with the cast marked, photographed and points traced on an overlay.

SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	0.627	0.786
L-K	0.736	2.311
Z-L	0.702	0.684
S-K	0.509	1.011
R-I	1.351	0.650
Mean: ± SEM n	**0.785** ± 0.147 5	**1.088** ± 0.312 5

Table 7 Comparison of Column E with Column B (see Table 1)

Self comparison of positive of the bitemark with the individual's dental cast. Reference points were marked on both the positive and the cast, then photographed and points traced on overlays placed on the photographs.		
SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	2.728	0.652
L-L	0.491	0.694
Z-L	0.753	0.474
S-K	0.514	2.156
R-I	0.389	1.637
Mean: ± SEM n	**0.975** ± 0.436 5	**1.123** ± 0.329 5

Table 8 The matching of a bitemark made by a subject on a flat wax matrix with a cast of the dentition of that subject. A comparative study of various ways of marking and digitising the reference points on cast and bitemark. This Table summarises the data from Tables 1 to 7.

Comparison between points marked on:	Table 1, Columns:	See Table #	n	Arch	Similarity Indices: Mean ± SEM	Range of values Min.	Range of values Max.
Photo. of wax bite & photo. of dental cast	C & A	2	11	U L	1.059 ± 0.082 1.029 ± 0.121	0.696 0.686	1.669 1.966
Photo. of positive of bite & photo. of dental cast	D & A	3	10	U L	0.880 ± 0.081 1.021 ± 0.131	0.604 0.582	1.308 1.787
Wax bite & dental cast	C & B	4	5	U L	1.053 ± 0.130 1.687 ± 0.366	0.680 0.774	1.367 2.716
Positive of wax bite & photo. of dental cast	E & A	5	5	U L	1.015 ± 0.237 1.382 ± 0.341	0.595 0.690	1.934 2.356
Photo. of positive of wax bite & dental cast	D & B	6	5	U L	0.785 ± 0.147 1.088 ± 0.312	0.509 0.650	1.351 2.311
Positive of wax bite & dental cast	E & B	7	5	U L	0.975 ± 0.436 1.123 ± 0.329	0.389 0.474	2.728 2.156
Photo. of dental cast & dental cast	--	28	5	U L	0.750 ± 0.083 0.901 ± 0.176	0.612 0.558	1.165 1.552
Photo. of dental cast & 2nd photo. of dental cast	--	19	7	U L	0.698 ± 0.064 0.667 ± 0.048	0.521 0.503	1.031 0.904
OVERALL VALUES:				MEAN: ± SEM n =	1.091 0.068 12	Min. = 0.389	Max. = 2.728

Table 9

'Self' and 'non-self' comparisons of a subject's flat wax bite with dental casts of the **upper** jaw of different subjects. Photographs of the cast and of the wax bite were taken and points marked on overlays placed on the photographs.

☐ = 'Non-self' comparisons (different subjects)

▣ = 'Self' comparisons (single subject) (data from Table 2)

SUBJECT CODE	Similarity Index (S.I) - DENTAL CAST (UPPER)										
	B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
B-S	**1.140**	4.607	5.027	5.323	4.388	3.843	5.946	5.217	5.958	2.537	3.692
J-Y	5.735	**0.816**	7.941	1.745	6.772	6.098	6.614	7.449	7.424	3.001	5.946
K-U	2.963	1.813	**1.048**	2.263	5.158	3.996	4.700	5.867	3.378	1.396	3.989
L-K	4.551	1.543	2.769	**0.975**	5.796	5.448	6.015	6.647	3.245	2.757	5.244
H-S	3.226	5.326	3.770	5.013	**1.048**	2.301	2.730	2.560	2.499	3.492	1.584
C-N	2.898	4.530	2.241	3.360	2.362	**1.669**	2.227	2.479	1.925	1.682	5.709
W-U	3.144	4.979	3.391	5.196	2.674	2.021	**1.133**	2.336	2.390	2.748	2.440
Z-L	3.757	5.016	4.018	5.201	1.994	1.885	1.927	**0.875**	2.767	4.191	2.018
S-K	4.179	2.194	2.945	2.244	4.237	3.496	4.440	4.815	**1.372**	2.330	3.379
R-I	2.460	2.118	6.537	2.374	4.184	3.639	3.975	5.022	2.457	**0.696**	3.342
A-D	3.095	4.990	3.112	4.581	1.775	1.402	1.913	2.317	1.528	2.615	**0.880**

Table 10

'Self' and 'non-self' comparisons of a subject's flat wax bite with dental casts of the **lower** jaw of different subjects. Photographs of the cast and of the wax bite were taken and points marked on overlays placed on the photographs.

☐ = 'Non-self' comparisons (different subjects)

☐ = 'Self' comparisons (single subject) (data from Table 2)

SUBJECT CODE	Similarity Index (S.I) - DENTAL CAST (LOWER)										
	B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
B-S	**0.814**	4.164	3.352	4.066	1.854	2.274	2.178	2.595	1.924	2.160	2.013
J-Y	4.785	**0.689**	1.837	1.665	5.554	6.085	5.385	6.017	3.987	2.945	5.097
K-U	3.949	2.121	**0.728**	2.286	4.552	4.672	4.088	4.698	2.995	1.983	4.120
L-K	6.417	2.434	2.943	**1.966**	6.460	7.225	6.945	7.292	5.388	4.339	6.633
H-S	1.797	5.431	4.030	5.414	**1.104**	1.383	1.878	2.486	2.090	2.868	1.246
C-N	1.675	5.891	4.224	5.837	1.594	**0.818**	1.528	1.860	1.917	3.116	1.512
W-U	2.136	5.295	3.920	5.875	2.617	2.074	**0.861**	1.640	2.890	2.893	2.234
Z-L	2.587	5.486	4.452	5.532	2.818	2.027	1.292	**0.761**	3.217	3.229	2.297
S-K	2.119	3.099	2.243	3.863	2.533	2.460	1.354	2.139	**0.876**	1.763	1.487
R-I	2.903	3.454	1.988	2.997	5.437	3.321	2.741	3.173	3.274	**1.123**	3.306
A-D	1.928	3.739	2.230	2.872	2.124	2.021	1.621	2.377	2.493	1.575	**1.243**

Table 11 Comparisons of a subject's bite into a flat wax matrix with a cast of that subject's dentition (self comparisons; n = 11) and with dental casts of 10 other subjects (non-self comparisons; n = 10 x 11 = 110).
This Table summarises the data found in Tables 9 and 10.

S.I. = Similarity Index (see text).

* 1.68 is the value of S.I. at the point of intersection (median of overlapping values) of the 'self' and 'non-self' distribution curves (Figure 15c).

† 2.00 is a convenient whole number which is close to the intersection point and might serve as an arbitrary value dividing what is considered 'self' and 'non-self'.

	Bitemark arch (analysed separately)	
	Upper	Lower
Number of non-self S.I. which were less than the 'correct' self S.I.	1/110	1/110
Number of non-self S.I. which were less than the highest self S.I. value obtained.	5/110	22/110
Number of non-self S.I. which were less than 1.68*	5/110	13/110
Number of self S.I. which were above 1.68*	0/11	1/11
Number of non-self S.I. which were less than 2.00†	14/110	24/110
Number of self S.I. which were above 2.00†	0/11	0/11
Lowest self S.I. recorded Highest self S.I. recorded Next highest S.I. recorded	0.696 1.669 1.372	0.689 1.966 1.243
Lowest non-self S.I. recorded Next lowest non-self S.I. recorded Highest non-self S.I. recorded	1.396 1.402 7.941	1.246 1.292 7.292

All digitising was done in a systematic manner, characterising molars, premolars, canine and incisor teeth, allowing for the fact that the lower first molars have one more cusp (5) than the upper first molars. Recording was commenced on the upper cast, with the arch shape facing the computer while, for the lower cast, the arch shape was facing away from the computer. The first tooth recorded for the upper cast was the upper left second molar, while for the lower cast it was the lower left second molar (see Figure 10).

For recording of wax bites or bite lesions, the overlay with reference points marked was turned over and then digitised. This is because the wax bites are the mirror-image of the dentition producing them, when the dentition is viewed from the incisal aspect.

It should be noted that, when two shapes are being compared, the computer program has a convenient feature built in that edits out any missing reference points such that only analogous points are matched.

Table 1 represents the master file of the subjects that were selected randomly. Initially, the casts of the eleven subjects were digitised from points marked on overlays placed on photographs of the casts. The points were then digitised and recorded in the computer (Table 1, Column A). A second set of data was recorded in the same format but, in this case, points were marked directly on the cast (see Figure 12), photographs taken and points traced on an overlay placed over the photograph. This second set, comprised a selected group of five subjects (Table 1, Column B). The third set of data, comprising all eleven subjects, was derived when their flat wax bites were photographed. Points were then marked on overlays, digitised and recorded on the computer (Table 1, Column C). The fourth set of data comprised ten subjects and was derived from stone models (positives) poured on the flat wax bites (Table 1, Column D). Data was obtained in a similar manner to that for the first set. The fifth set of data was similar to the second set, except that the points were marked directly on the positives, photographed and the points then traced on overlays placed over the photographs (Table 1, Column E).

The comparisons made between these groups are summarised below;

(i) Comparison of Column C with Column A

As an initial ideal derivation of a match, for each subject in a group of 11, a comparison between the flat wax bite impression and the dental cast of the person who actually produced that impression. For ease of description, these comparisons were termed as 'self' (Table 2). In another trial, wax bite impressions were also compared with dental casts taken from other subjects (i.e. non-perpetrators). These matches were classified as 'non-self' (Tables 9, 10 and 11).

(ii) Comparison of Column D with Column A.

This 'self matching' was to determine if there is an improved result with the match of the positives derived from flat wax bites when compared with casts. In this situation, photographs of casts and of positives were taken and points marked on overlays placed on the photographs (Table 3).

(iii) Comparison of Column C with Column B.

The 'self matching' of points from the flat wax bite which were marked directly on overlays and compared with dental casts marked, photographed and points traced on overlays (Table 4).

(iv) Comparison of Column E with Column A.

Points were marked on positives of flat wax bites and photographs taken. Subsequently, points were traced on overlays placed on the photographs which were then compared with dental casts photographed and points marked on overlays placed on the photographs (Table 5).

(v) Comparison of Column D with Column B.

Positives of flat wax bites were photographed and points marked on overlays. These were compared with the casts with points marked and photographed. Points were then traced on overlays placed on these photographs (Table 6).

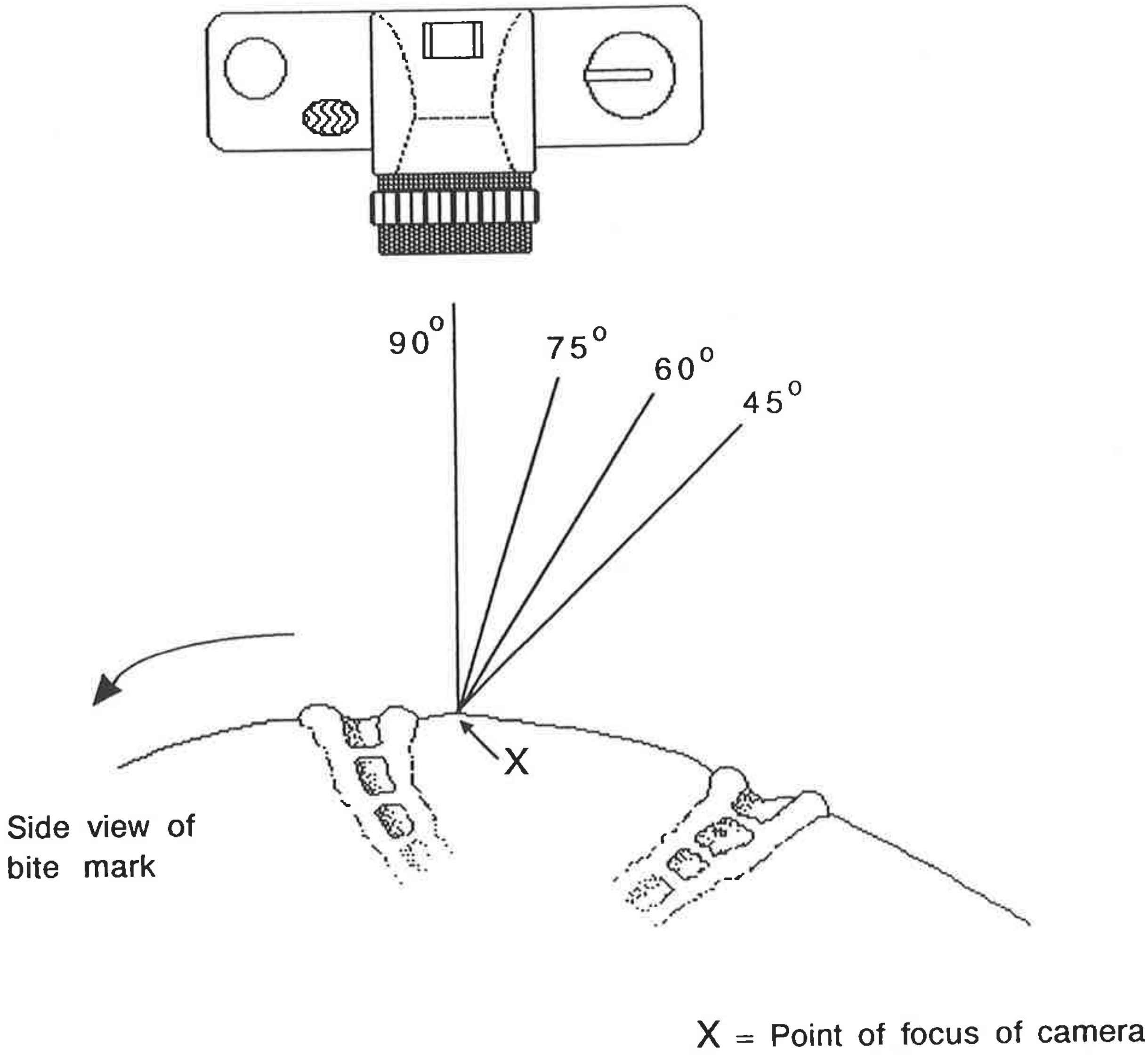
(vi) Comparison of Column E with Column B.

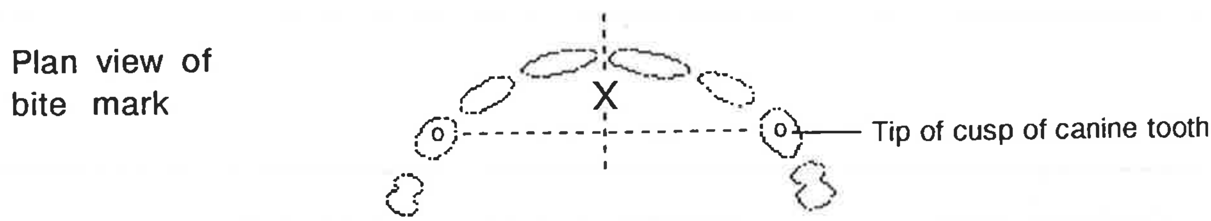
Points were marked on the positives of flat wax bites and photographed. These were then traced on overlays and compared with the dental casts marked, photographed, and the points traced on overlays placed on these photographs (Table 7).

Figure 13

Diagram showing camera angles used to photograph each arch of a bitemark on skin or curved wax surfaces.

The camera position was fixed and the object was rotated to present the four angles of incidence selected as references in this study. When both arches were photographed together, the camera was set at 90° and focussed on the mid-point between the arches (i.e the centre of the bitemark).





Legend for Tables 12 to 16 inclusive

Comparisons of individual arch bites on a curved wax matrix with the dental casts of the 'perpetrator' (self) and of other subjects (non-self).

Data given are the Similarity Indices (S.I.) from comparisons of bitemarks, photographed at various angles, with the dental casts of 'self' and 'non-self'.

Figures enclosed by a box indicate results obtained with matches from 'self' comparisons.

Values underlined indicate the best match or 'fit' obtained in a series of comparisons.

No values are given for instances where it was not possible to make a meaningful comparison due to inability to distinguish reference points on the photographs.

Data in Tables 12 to 16 are summarised in Table 17 and the collated 'self' and 'non-self' matches are compared in Table 18. The numbers of correct and incorrect matches resulting from these comparisons are listed in Table 18.

Table 12

Results from photographs of the **upper** bite arch taken at different angles, i.e. at 90°, 75°, 60°, 45° and when both arches are together. Reference points were marked on an overlay placed on the photograph.

SUBJECT CODE		B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
	90	0.581	2.288	2.697	2.294	2.787	3.507	3.282	3.715	2.358	2.284	2.755
	75	1.563	2.109	2.728	2.429	4.372	4.175	3.819	4.928	3.138	2.334	3.250
B-S	60	2.399	3.181	3.838	3.589	5.211	5.040	4.035	5.060	4.591	3.216	4.459
	45	0.626		0.642		0.386	0.129	0.116	1.002	0.939	0.348	0.827
	U arch	2.781	3.755	4.269	4.551	5.374	5.797	4.664	5.954	4.801	3.647	5.120
	90	2.325	0.806	1.929	1.916	2.643	3.497	2.196	3.052	1.950	1.693	2.455
	75	2.521	0.647	2.119	2.145	2.939	3.731	2.524	3.525	2.077	1.535	2.550
J-Y	60	3.788	2.271	2.681	3.637	4.481	4.746	3.181	4.469	3.480	2.484	3.841
	45											
	U arch	3.503	1.897	2.783	3.190	4.063	4.314	2.736	4.051	3.017	2.085	3.366
	90	0.840	1.727	0.898	0.982	1.472	1.333	1.886	1.645	1.279	1.399	1.026
	75	1.047	1.464	1.089	0.949	1.191	1.400	1.506	1.514	0.845	1.067	0.732
K-U	60	1.388	1.419	1.344	1.069	1.797	1.304	1.073	1.604	0.836	0.746	0.873
	45											
	U arch		2.821	4.385	4.616	6.084	6.915	5.003	6.466	4.456	4.142	5.907
	90	1.921	1.457	1.022	0.951	1.568	2.210	1.657	1.947	1.184	1.128	1.448
	75	1.787	1.656	1.225	1.226	1.787	2.231	1.510	2.216	1.148	1.051	1.531
L-K	60	1.977	1.575	1.759	1.523	1.455	1.984	1.010	2.274	1.495	0.816	1.226
	45	1.692	1.043	1.669	1.422	1.971	1.510	0.903	1.822	1.445	0.890	1.019
	U arch	1.663	1.519	1.092	1.062	1.712	2.243	1.671	2.384	1.428	0.940	1.501
	90	1.461	1.452	1.026	0.886	0.781	1.510	1.050	1.431	0.759	0.650	0.773
	75	1.602	1.800	1.010	1.369	1.082	2.138	1.769	2.028	1.021	1.457	1.151
H-S	60	2.494	1.322	1.843	1.366	1.951	2.477	1.189	2.464	0.969	1.044	1.493
	45		2.125	0.501	0.067	0.359	1.738	0.280	1.713	0.547	0.710	0.764
	U arch	2.315	1.896	2.160	1.840	2.113	2.399	1.289	2.560	1.562	1.178	1.623

Table 13

Photographs of **upper** bite arch taken at different angles, i.e. 90°, 75°, 60°, 45° and when both arches are together. Reference points marked on an overlay placed on the photograph.

SUBJECT CODE		B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
	90	1.243	3.058	3.208	1.960	2.170	0.721	1.944	1.517	2.567	2.989	1.392
	75	1.370	2.754	2.858	1.734	2.074	0.696	1.556	1.419	2.301	2.693	1.392
C-N	60	1.912	2.901	2.770	2.614	3.397	1.938	1.637	2.865	3.056	2.556	2.106
	45	0.840	4.401	2.465	3.938	3.687	2.146	2.434	2.972	3.595	3.544	2.654
	U arch	2.294	3.212	3.309	2.906	4.227	2.857	2.326	3.396	3.826	3.011	3.104
	90	2.164	1.395	1.858	1.958	2.321	2.764	0.920	2.376	1.366	1.390	1.760
	75	2.533	1.322	2.430	2.372	2.783	3.358	1.477	3.023	1.806	1.382	2.370
W-U	60	2.909	2.166	2.781	3.037	3.720	3.726	1.935	3.419	2.671	1.951	2.992
	45											
	U arch	2.972	1.631	2.562	3.046	3.014	3.610	1.762	3.188	2.383	1.952	2.987
	90	1.925	1.657	1.654	1.453	1.622	1.716	1.440	0.835	1.196	1.434	1.200
	75	1.900	1.839	1.654	1.461	1.599	1.633	1.532	0.801	1.381	1.596	1.228
Z-L	60	2.222	1.101	1.679	1.845	1.670	1.908	0.786	0.649	0.881	0.985	1.479
	45	1.036	2.445	2.444	2.633	2.173	2.588	1.518	1.183	2.204	1.758	2.099
	U arch	2.943	2.129	2.924	2.717	2.215	2.534	1.459	1.565	2.020	1.934	1.947
	90	2.228	1.330	1.654	1.362	2.069	2.329	1.678	2.033	0.947	1.581	1.489
	75	1.904	1.787	1.397	1.270	1.760	2.273	1.397	2.003	0.743	1.210	1.309
S-K	60	1.878	1.417	1.570	1.452	1.896	2.224	1.312	2.175	0.946	1.013	1.407
	45	2.055	1.318	2.010	2.177	2.737	3.023	1.502	2.352	1.722	1.212	2.446
	U arch	2.297	1.143	2.160	2.121	2.896	2.949	1.536	2.305	1.863	1.125	2.394
	90	2.229	0.916	1.499	1.539	2.328	2.516	1.473	2.588	1.565	0.721	1.638
	75	2.206	0.948	1.570	1.848	2.624	3.182	1.925	3.074	1.763	0.939	2.169
R-I	60	2.960	1.704	2.191	2.893	3.577	3.816	2.243	3.649	2.630	1.696	3.017
	45	2.206	0.346	1.927	2.870	2.866	4.457	2.361	4.143	2.031	2.144	3.435
	U arch	2.394	1.610	2.238	2.837	3.947	4.822	3.116	4.709	3.012	1.938	3.769

Table 14

Photographs of **upper** and **lower** bite arches (subject A-D) taken at different angles i.e. 90°, 75°, 60°, 45° and when both the arches are together. Reference points marked on an overlay placed on the photograph.

SUBJECT CODE		B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
A-D	90	1.037	2.085	1.079	1.090	1.406	1.741	1.498	1.681	0.932	1.301	0.611
	75	1.121	2.374	1.463	1.376	1.428	1.590	1.430	1.717	1.017	1.411	0.482
	60	2.067	2.370	2.148	2.288	2.778	2.175	1.171	2.631	1.927	1.643	1.608
	45	2.088	3.152	1.116	2.344	3.594	3.426	2.041	3.552	2.341	2.068	2.436
	U arch	2.608	3.029	0.414	2.381	3.523	3.387	2.131	3.324	2.237	2.109	2.346
A-D	90	1.215	0.977	1.076	0.975	1.314	0.877	0.790	1.601	1.327	0.792	0.661
	75	1.152	0.896	1.047	1.093	1.489	1.191	1.157	1.862	1.737	0.605	1.110
	60	1.482	1.178	1.706	1.089	2.191	1.712	0.841	1.459	2.059	1.215	1.063
	45	0.765		0.279	3.049	0.557	0.498	0.389	2.168	0.099	1.132	0.420
	L arch	2.323	1.312	1.514	1.827	2.425	2.139	1.087	2.588	1.173	2.176	2.168

Table 15

Photograph of **lower** bite arch taken at different angles i.e. 90°, 75°, 60°, 45° and when both arches are together. Reference points marked on an overlay placed on the photograph.

SUBJECT CODE		B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
	90	0.816	3.349	1.411	1.562	1.912	2.297	2.139	2.525	2.435	1.260	1.838
	75	0.902	3.190	1.313	1.121	1.797	2.038	1.544	2.139	2.123	1.221	1.395
B-S	60	2.348	3.051	1.126	1.250	2.471	3.111	2.562	3.563	2.961	1.906	3.046
	45	3.120	0.136	2.576	2.892	4.252	5.056	4.597	5.678	3.981	3.256	5.866
	L arch	1.784	1.899	1.902	1.180	3.005	3.064	2.740	3.874	2.964	1.753	3.380
	90	2.050	1.994	2.172	1.967	3.015	2.556	2.134	2.638	2.621	1.987	2.349
	75	2.479	1.412	2.655	1.927	3.952	3.633	2.537	2.866	3.341	2.087	3.070
J-Y	60											
	45											
	L arch	1.929	0.562	0.935	0.580	1.030	0.720	0.681	0.983	1.192	0.641	0.263
	90	1.547	1.631	0.709	1.602	0.787	0.716	1.478	2.203	1.167	1.410	1.249
	75	1.286	1.269	0.668	1.137	0.915	0.760	1.071	1.939	0.956	0.886	0.885
K-U	60	1.014	1.493	0.677	0.767	0.735	0.425	0.470	1.704	1.165	1.116	0.571
	45	0.537	0.875	1.108	0.348	1.014	1.052	0.789	2.267	0.317	0.923	1.315
	L arch	4.479	5.391	3.385	4.154	3.456	3.765	4.069	3.768	3.706	4.915	3.882
	90	1.772	1.560	1.975	1.122	2.145	2.114	1.550	2.089	2.312	1.440	1.555
	75	1.772	1.510	2.602	1.702	3.175	2.814	1.612	1.946	2.695	1.936	2.076
L-K	60	2.449	1.588	2.485	1.577	2.918	2.729	2.013	2.561	2.933	2.164	2.144
	45	0.157		0.738	1.390	1.454	1.552	0.950	3.140	1.350	0.100	1.688
	L arch	1.745	1.387	2.014	0.875	2.501	2.142	1.367	1.906	2.327	1.376	1.538
	90	1.480	1.344	0.807	1.584	0.670	0.559	1.345	1.988	1.034	1.261	1.107
	75	1.501	1.128	1.011	0.935	1.243	1.088	1.006	1.978	1.081	0.705	0.921
H-S	60	1.566	1.849	1.591	1.391	2.127	1.672	0.914	1.706	1.935	1.449	1.312
	45	0.924	2.409	0.329	1.329	0.442	0.460	0.735	0.835	1.199	2.471	0.254
	L arch	1.478	1.037	1.606	0.844	1.860	1.530	0.809	1.851	1.601	0.784	0.913

Table 16

Photograph of **lower** bite arch taken at different angles i.e. 90°, 75°, 60°, 45° and when both arches are together. Reference points marked on an overlay placed on the photograph.

SUBJECT CODE		B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
	90	1.501	2.917	0.816	1.515	1.501	0.742	1.438	1.999	1.616	1.372	1.296
	75	1.955	2.573	0.796	1.386	1.866	0.911	1.284	1.787	1.794	1.169	1.178
C-N	60	1.741	1.564	1.542	1.071	2.224	1.776	1.112	1.592	2.347	1.218	1.458
	45	1.474		0.722	0.503	1.891	1.939	0.510	1.637	0.861	1.640	1.717
	L arch	2.285	2.099	1.713	1.265	3.095	2.148	1.653	1.999	2.308	1.306	2.025
	90	1.631	1.823	1.724	1.223	2.301	1.877	0.734	1.541	2.327	1.027	1.287
	75	1.406	1.621	1.533	1.368	2.070	1.783	1.144	1.817	2.324	0.799	1.512
W-U	60	2.206	2.428	1.384	1.395	2.733	2.535	1.782	2.011	2.695	1.069	2.265
	45											
	L arch	2.254	1.639	2.092	1.530	2.937	2.712	1.541	2.028	2.865	1.709	2.146
	90	1.630	1.623	2.655	1.925	2.963	2.361	1.342	1.562	2.618	1.725	1.459
	75	1.745	3.493	2.012	2.064	2.221	1.894	1.240	0.768	2.003	1.840	1.412
Z-L	60	1.624	1.994	1.997	1.920	2.200	1.771	1.201	0.788	2.095	1.732	1.282
	45	2.494	1.750	3.346	2.347	3.663	3.147	2.061	2.221	3.142	2.207	2.382
	L arch	1.834	1.854	2.287	1.652	2.692	2.446	1.261	1.445	2.261	1.819	1.666
	90	1.567	1.117	1.189	0.760	1.315	1.083	0.952	1.927	1.232	0.700	0.910
	75	1.711	1.560	1.709	0.972	1.724	1.564	1.227	1.965	1.650	0.973	1.230
S-K	60	3.588	3.683	4.398	3.638	4.358	4.239	3.546	3.158	4.698	3.472	3.475
	45	2.698	1.046	3.339	1.657	3.189	3.047	2.744	4.514	2.297	0.945	3.107
	L arch	2.320	0.722	2.946	1.469	2.809	2.707	2.413	4.117	1.960	0.633	2.812
	90	1.563	0.735	1.755	1.030	2.099	1.685	1.372	1.973	1.957	0.959	1.344
	75	1.876	1.089	2.311	2.067	2.697	2.313	1.901	2.160	2.697	1.485	1.964
R-I	60	1.431	0.982	1.975	1.190	2.108	1.730	1.196	1.806	2.162	0.927	1.174
	45	1.620	0.270	2.172	1.613	2.094	2.178	1.925	3.327	1.447	0.233	2.488
	L arch	1.043	1.437	2.143	1.275	2.114	1.722	1.399	1.742	2.374	0.748	1.326

Table 17

Summary of data for comparisons of a bitemark (upper and lower arches analysed separately) made by each subject on a curved surface with dental casts of 10 other subjects, i.e non-self comparisons. The data also show the effects of varying the camera angle during photography on the Similarity Index derived from these comparisons. This Table summarises the data found in Tables 12 to 16.

Camera angle, degrees		Similarity Index (S.I.)										
		B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D
UPPER	90	2.797	2.366	1.359	1.554	1.099	2.205	1.935	1.530	1.775	1.829	1.385
	75	3.338	2.567	1.172	1.614	1.317	2.015	2.338	1.582	1.631	2.131	1.492
	60	4.222	3.679	1.211	1.585	1.666	2.581	2.937	1.456	1.634	2.868	2.120
	45	0.549†	0/10	0/10	1.522	0.938*	3.053	0/10	2.090	2.083	2.664	2.572
	U/L	4.793	3.312	5.157*	1.615	1.882	3.161	2.735	2.282	2.093	3.245	2.514
LOWER	90	2.073	2.367	1.379	1.851	1.251	1.597	1.825	2.030	1.205	1.513	1.094
	75	1.788	2.855	1.110	2.214	1.135	1.579	1.623	1.992	1.531	2.060	1.223
	60	2.605	0/10	0.946	2.398	1.539	1.587	1.848	1.782	3.878	1.551	1.493
	45	3.829	0/10	0.944	1.237*	1.095	1.216*	0/10	2.654	2.764	1.688	0.993*
	U/L	2.576	0.895	4.159	1.830	1.245	1.975	2.146	1.977	2.428	1.600	1.856

n = 10 except where figures are marked * when n = 9 and marked † when n = 8

Table 18 Overall summary of results from comparisons of bitemarks made on a curved surface using different camera angles.

Self matches give the Similarity Indices (S.I.) resulting from comparisons of the dental cast of a subject with the bitemark (upper and lower arches were studied separately) made by that same subject biting on a standard curved wax matrix (n = 11 subjects).
Non-self matches give the Similarity Indices resulting from comparisons of these arch marks with 10 dental casts taken from persons other than the actual 'perpetrator'.
A correct or successful match or 'fit' was recorded for each bitemark only when the self S.I. value was lower than <u>all</u> non-self S.I. values. An incorrect match was recorded in each case where <u>any</u> non-self S.I. value was less than the corresponding 'correct' S.I. value.
Camera angles marked * are those at which the mean self S.I. were within the accepted limits (<1.68, see text) and statistically significantly lower at the 5% level than the corresponding non-self values.

Arch of bite mark	Camera angle, degrees	Similarity Indices (Mean ± SEM)			Number of matches based on S.I. value which proved to be;	
		Self comparisons, n = 11 subjects	Non-self comparisons, n = 10 means (each from11 subjects)	Non-self / Self	Correct	Incorrect
UPPER	90*	0.797 ± 0.039	1.803 ± 0.150	2.26	9	2
	75*	0.977 ± 0.104	1.926 ± 0.191	1.97	7	4
	60	1.660 ± 0.160	2.360 ± 0.296	1.42	6	5
	45	1.505 ± 0.265	1.934 ± 0.308	1.28	0	8
	U/L	2.234 ± 0.265	2.981 ± 0.302	1.33	2	9
LOWER	90*	1.005 ± 0.135	1.653 ± 0.123	1.64	6	5
	75*	1.163 ± 0.120	1.737 ± 0.158	1.49	4	7
	60	1.678 ± 0.265	1.963 ± 0.260	1.17	3	7
	45	1.560 ± 0.313	1.824 ± 0.340	1.17	1	8
	U/L	1.612 ± 0.244	2.062 ± 0.255	1.28	3	8

6. Photographing bites made on a curved wax surface

A study was undertaken to determine the ideal camera angle for taking photographs of a bitemark on a curved wax surface. The upper and lower arches of the bitemarks were each photographed at different angles of incidence, 90°, 75°, 60°, 45°, and then a photograph was taken at 90° of both bite arches together (see Figure 13). For these photographs, it was decided that, for the individual arch photographs, the point of focus would be the midpoint of a line perpendicular to a line drawn between the cuspal tips of both canines and passing between the central incisors, i.e. through the midline, of the individual arch (Figure 13). This reference focal point was also employed during photography at the different angles of incidence. These were obtained by rotating the bitemark to the specified angles, relative to the fixed camera, with the aid of a protractor.

Subsequently, reference points for digitising of the incisal and cuspal indentations were traced on an overlay upon these photographs, as performed with the flat wax bite. Comparison of each individual arch bite with the dental cast of different students was then made. In the case where both arches had been photographed together at 90°, the upper and lower arches were distinguished and separate comparisons made (for results, see Tables 12 to 18).

7. Assessment of errors inherent in the methodology.

a. An attempt was made to determine any measurable distortion produced by the position of the cast in the box in which it is photographed. A cast was positioned as normal on the surveyor table and then placed in the box for photographing. The camera was focussed on to the scale bar in the centre of the box. A series of photographs was taken as the box containing the cast was moved and the scale bar was repositioned from one side of the camera field of view to the other on the metallic table of the rack. During this process, the camera focus was not altered. The negatives were then developed in the normal way. The negative of the scale bar in the central (normal) position was printed first. The height of the enlarger was adjusted such that the image produced was life size. Once the scale bar was focussed in the enlarger, neither the focussing nor the enlarger height was subsequently altered for other negatives.

When the scale bar was in the position that two casts would occupy if they were

Table 19 The reproducibility of photographing and digitising points from dental casts.

Two photographs were taken of each dental cast from seven subjects, the reference points were marked and the duplicate sets of data were compared by applying the shape analysis algorithm and calculating the Similarity Index

SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
J-Y	0.608	0.603
L-K	0.521	0.620
H-S	0.784	0.904
C-N	1.031	0.737
W-U	0.619	0.673
Z-L	0.714	0.631
K-U	0.612	0.503
Mean: **± SEM** **n**	**0.698** **± 0.064** **7**	**0.667** **± 0.048** **7**

placed on either side of the central mark, no measurable distortion of the scale bar was detected. Only when tests were made with the casts placed in extreme positions, i.e. at the very edge of the field of view, was distortion detectable with the maximum distortion being in the order of 0.25 mm.

Throughout this project, casts were invariably placed centrally so it can be safely assumed that there was no significant distortion of the casts with respect to its position when being photographed.

b. The presence of any distortion introduced by the position of the negative in the enlarger was investigated. A single negative was positioned in the enlarger frame with the negative in the most anterior position. The scale bar was focussed and this focus remained unchanged for the procedure. The paper was exposed and the length of exposure remained constant for all the prints. The negative was then positioned in its most posterior position and the process repeated. A third print was made with the negative in a central position.

It was found that there was good agreement between the length of the scale bar in all three prints. It could be assumed, therefore, that any distortion introduced by the position of the negative in the enlarger frame was negligible.

c. The amount of subjective error when taking photographs and marking reference points was determined. Casts of seven randomly selected students were photographed twice using the same photographic procedures. Prints were made and the reference points were marked on the overlay. The reference points were then digitised and recorded in the computer. A comparison of the data from the two images was then made.

It can be seen from Table 19 that the Similarity Index between two upper or two lower arches ranged from around 0.5 to 1.0 mm, with a similar mean and variation for the upper (0.70) and lower (0.67) arches. These values were well within the range of those obtained under the 'self' matching procedure with the mean indices being lower than the majority of 'self' values. It can be concluded that the degree of subjective error during photography and marking of reference points did not distort the indices derived from comparisons.

d. Any difference occuring in measured values after 20 months was estimated by taking new flat wax bites and comparing them with original casts of the

Table 20 The reproducibility of estimates after a 20 month interval.

To determine if there is any difference of values when new flat wax bites are taken and compared with the dental cast. This also determines if any difference in the lighting setup would alter the values obtained.

SUBJECT CODE	UPPER JAW			LOWER JAW		
	SIMILARITY INDEX (SI)		Later values as % of initial estimates.	SIMILARITY INDEX (SI)		Later values as % of initial estimates.
	Initial estimate	20 months later		Initial estimate	20 months later	
B-S	1.140	0.892 0.908	78 80 } 79	0.814	1.360 0.935	167 115 } 141
L-K	0.975	0.973 1.116	100 114 } 107	1.966	1.265 0.926	64 47 } 56
Z-L	0.875	0.735	84	0.761	0.939	123
R-I	0.696	0.941	135	1.123	1.052	94
		Mean ± SEM	99 ± 9 (6)			102 ± 18 (6)
		Overall mean ± SEM	100 ± 10 (12)			

dentition of the 'perpetrators'. This would allow for any changes in the dentition of the subject over this period. The experiment would also determine if different values would be produced by any slight changes in the photographic set-up (e.g. angle of the spotlights or position of the camera) when photographs are taken on different occasions.

Photographs of flat wax bites of four randomly selected subjects were taken by the established method. In two cases duplicate re-assessments were performed. In most cases, the values obtained (Table 20) were very similar to the original results. The closeness of the values (mean difference is 100 ± 10%) confirms the likelihood of achieving the same match after an interval of nearly two years.

Clearly, any differences in the positioning of the spotlights or camera between the two occasions did not result in any marked differences from the values that were obtained originally. The greatest difference was in the case of subject L-K where the satisfactory later indices (1.27 and 0.93) were nearly half of the original value (1.97). It should be noted, however that this value of 1.97 remains the highest value for a Similarity Index that we have obtained from a 'self' comparison in these experiments. Nonetheless, all of the 20-month values were within 44% of the respective original assessments, which figure is itself within the experimental variability (3 to 45%) between duplicate comparisons made within minutes of each other (Table 20).

8. Bitemarks in foodstuffs

The suitability of using the shape analysis methodology on bitemarks produced on selected foodstuffs was investigated. For the initial studies, a small series of four common foodstuffs was chosen. These were;

a. eating apple (Red Jonathon), representing a 'crisp' bite,
b. cheese (Kraft "Coon" processed cheddar, 20gm), representing a 'plastic' bite,
c. chocolate-coated confectionery bar (Rowntree "Mars" bar, which contains sugar, full-cream milk solids, cocoa fat, cocoa mass, lecithin, flavour, vegetable fats, malt extract, salt and egg white), representing the complex bite produced in a non-homogeneous food product, and
d. chewing gum (two pieces of Wrigley's "Arrowmint", which contains sugar, gum base, glucose syrup, anti-oxidant), representing a 'chewy' bite.

Table 21 Experimental bitemarks made in different foodstuffs.

Figures enclosed by a box are Similarity Indices(S.I.) obtained with self matching. Values underlined indicate the best match or 'fit' (i.e. the lowest S.I. value) obtained for each arch in a series of comparisons with each foodstuff. These data are summarised in Tables 25 and 26.

Self matching of foodstuffs bitten by subject B-S and non-self comparisons with dental casts of other subjects.

Foodstuff	Dental arch	B-S	L-K	R-I	Z-L
Apple	Upper	1.651	1.269	1.689	<u>1.112</u>
	Lower	It was not possible to discriminate any tooth marks.			
Cheese	Upper	1.172	<u>0.629</u>	0.991	1.541
	Lower	<u>0.585</u>	1.024	0.765	0.693
Chewing gum	Upper	0.973	0.869	<u>0.452</u>	0.952
	Lower	<u>0.798</u>	1.546	1.370	1.332
Chocolate confectionery bar	Upper	It was not possible to discriminate any tooth marks.			
	Lower	It was not possible to discriminate any tooth marks.			

Table 22 Experimental bitemarks made in different foodstuffs.

Figures enclosed by a box are Similarity Indices(S.I.) obtained with self matching. Values underlined indicate the best match or 'fit' (i.e. the lowest S.I. value) obtained for each arch in a series of comparisons with each foodstuff. These data are summarised in Tables 25 and 26.

Self matching of foodstuffs bitten by subject L-K and non-self comparisons with dental casts of other subjects.

Foodstuff	Dental arch	B-S	L-K	R-I	Z-L
Apple	Upper	1.830	1.476	1.284	1.827
	Lower	It was not possible to discriminate any tooth marks.			
Cheese	Upper	1.775	0.858	0.548	1.104
	Lower	1.093	0.670	0.577	1.129
Chewing gum	Upper	1.351	1.058	0.663	1.370
	Lower	1.467	0.529	0.487	1.144
Chocolate confectionery bar	Upper	It was not possible to discriminate any tooth marks.			
	Lower	It was not possible to discriminate any tooth marks.			

Table 23 Experimental bitemarks made in different foodstuffs.

Figures enclosed by a box are Similarity Indices(S.I.) obtained with self matching. Values underlined indicate the best match or 'fit' (i.e. the lowest S.I. value) obtained for each arch in a series of comparisons with each foodstuff. These data are summarised in Tables 25 and 26.

Self matching of foodstuffs bitten by subject R-I and non-self comparisons with dental casts of other subjects.

Foodstuff	Dental arch	B-S	L-K	R-I	Z-L
Apple	Upper	1.549	1.097	<u>0.906</u>	1.387
	Lower	1.422	<u>0.670</u>	0.912	1.315
Cheese	Upper	1.777	1.357	<u>0.684</u>	1.443
	Lower	1.038	<u>0.565</u>	2.699	0.882
Chewing gum	Upper	2.633	2.286	<u>1.328</u>	2.013
	Lower	0.981	0.795	<u>0.454</u>	0.877
Chocolate confectionery bar	Upper	It was not possible to discriminate any tooth marks.			
	Lower	It was not possible to discriminate any tooth marks.			

Table 24 Experimental bitemarks made in different foodstuffs.

Figures enclosed by a box are Similarity Indices(S.I.) obtained with self matching. Values underlined indicate the best match or 'fit' (i.e. the lowest S.I. value) obtained for each arch in a series of comparisons with each foodstuff. These data are summarised in Tables 25 and 26.

Self matching of foodstuffs bitten by subject Z-L and non-self comparisons with dental casts of other subjects.

Foodstuff	Dental arch	B-S	L-K	R-I	Z-L
Apple	Upper	1.807	0.757	0.793	1.112
	Lower	1.161	1.086	1.127	1.059
Cheese	Upper	1.933	1.547	0.825	0.947
	Lower	1.289	1.539	1.833	1.276
Chewing gum	Upper	1.411	1.393	1.142	1.069
	Lower	0.625	1.149	1.006	0.648
Chocolate confectionery bar	Upper	It was not possible to discriminate any tooth marks.			
	Lower	It was not possible to discriminate any tooth marks.			

Table 25 Comparisons of experimental bitemarks in various foodstuffs with the dental casts of the perpetrator and of 3 other subjects. Only the best non-self match, i.e. the lowest Similarity Index (S.I.) value, of the three subjects was chosen for each foodstuff from the data to be found in Tables 21 to 24.

Foodstuff	S.I. values from comparison of:		B-S	L-K	R-I	Z-L	Matches made	Matches made /total
Apple	Self	U L	1.651 --	1.476 --	0.906 0.912	1.112 1.059	1 1	2 / 6
	Best non-self	U L	1.112 --	1.284 --	1.097 0.670	0.757 1.086	3 1	4 / 6
Cheese	Self	U L	1.172 0.585	0.858 0.670	0.684 2.699	0.947 1.2760	1 2	3 / 8
	Best non-self	U L	0.629 0.693	0.548 0.577	1.357 0.565	0.825 1.289	3 2	5 / 8
Chewing gum	Self	U L	0.973 0.798	1.058 0.529	1.328 0.454	1.069 0.648	2 2	4 / 8
	Best non-self	U L	0.452 1.332	0.663 0.487	2.013 0.795	1.142 0.625	2 2	4 / 8
Chocolate confectionery bar	Self	U L	-- --	-- --	-- --	-- --	0 0	0 / 0
	Best non-self	U L	-- --	-- --	-- --	-- --	0 0	0 / 0
Totals:	n = Correct matches: Incorrect matches:		5 2 3	5 0 5	6 4 2	6 3 3		22 9 13

Table 26 Summary of results from experimental bitemarks in different foodstuffs. This Table summarises the data from Table 25.

Foodstuff	Dental arch	Number of correct matches	Correct matches		Incorrect matches	
			Number	%	Number	%
Apple	Upper	1	2 of 8	33	6 of 24	67
	Lower	1				
Cheese	Upper	1	3 of 8	38	8 of 32	62
	Lower	2				
Chewing gum	Upper	2	4 of 8	50	6 of 32	50
	Lower	2				
Chocolate confectionery bar	Upper	No matching was possible due to inadequate registration of bite				
	Lower	No matching was possible due to inadequate registration of bite				

Figure 14 Experimental bitemark produced on the arm of a volunteer.

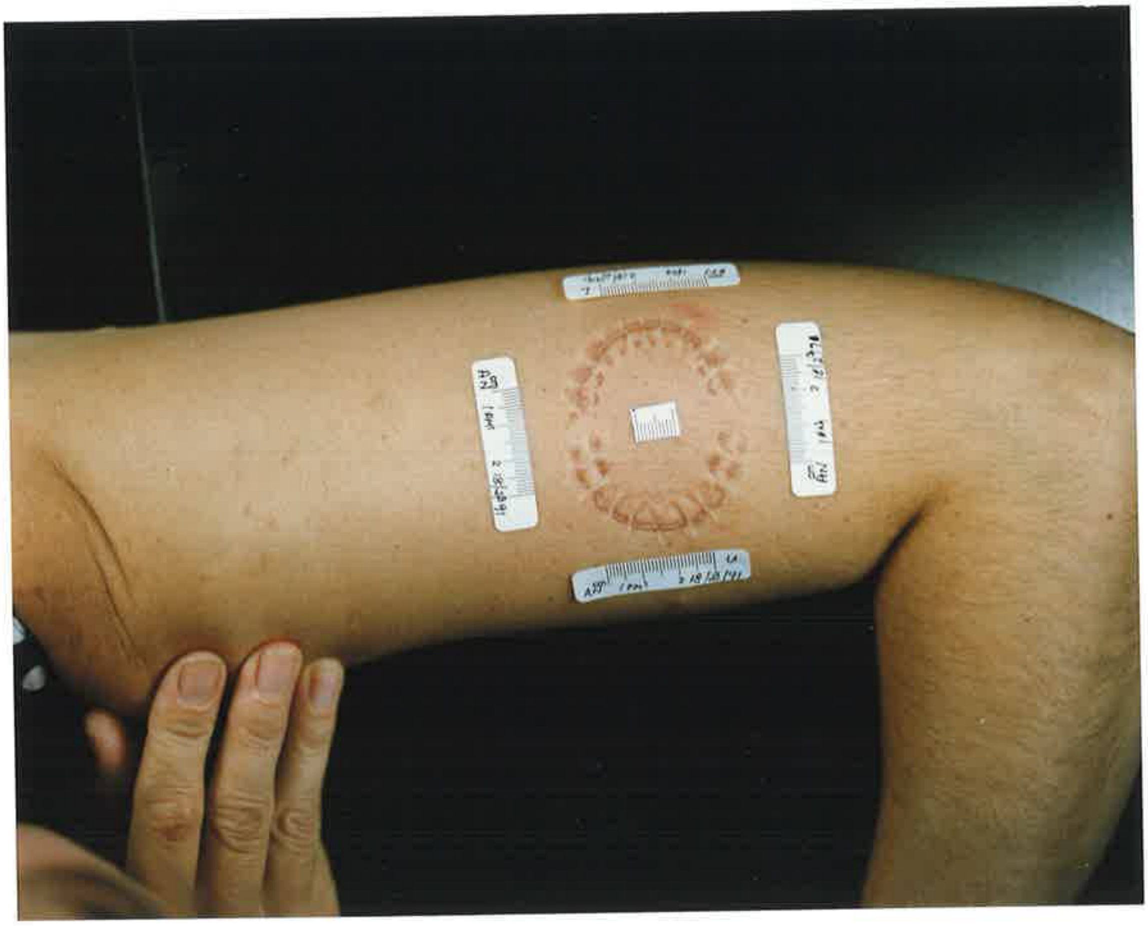


Table 27 Experimental bitemark made on human skin.

These Similarity Indices (S.I.) were obtained when the upper arch bite produced on the skin was compared with the upper dental casts of the perpetrator (subject T-R) and other subjects. The value underlined is the lowest S.I. obtained in this series and thus indicates the best match or 'fit'

SUBJECT CODE	Similarity Index	
	UPPER JAW	
B-S	2.708	Mean S.I. from 11 non-self matches is: **2.049 ± 0.151** (SEM)
J-Y	1.483	
K-U	2.202	
L-K	1.933	
H-S	2.119	
C-N	2.945	
W-U	1.790	
Z-L	2.513	
S-K	1.492	
R-I	1.532	
A-D	1.823	
T-R	<u>1.201</u>	

Four subjects were requested to make a firm, normal bite in each item of food such that the anterior teeth marks were reproduced and a quantity of the material was removed with the bite. With the chewing gum, the subjects were requested to chew the mass until pliable and then to make an impression with the anterior teeth. Photographs were taken using the same procedures as with the previous flat wax bites. The processing of the film and making of the prints followed the standard procedure. Each upper or lower bitemark was compared with the dental cast of the 'perpetrator' (self match) and with dental casts of three other subjects (non-self match). The individual results are shown in Tables 21 to 24 and are summarised in Tables 25 and 26.

9. Bitemarks on the skin.

As an additional facet of these investigations, the usefulness of the computer program in the analysis of bitemarks produced on the skin was ascertained.

An experimental bite was inflicted over the biceps muscle of a volunteer (Figure 14). In this situation, the upper arch was photographed immediately with a camera angle of 90°. Subsequently, the film was processed and the print enlarged to life size. Reference points were then marked on an overlay placed on the photograph, digitising was performed and the data recorded in the computer.
Comparisons of the casts of all the subjects involved in the earlier experiments were performed to find any suitable match. Subsequently, the cast of the actual 'perpetrator' was also compared (Table 27).

D. RESULTS

1. Evaluation of the Similarity Index using flat wax bite comparisons with 'self' and 'non-self'.

The initial determination was the comparison of flat wax bites with the casts of the 'perpetrators' (Tables 1 and 2, Column C with Column A). It is observed that the mean Similarity Index (SI) values of both the upper (1.06) and the lower (1.03) arches were close to 1.0 mm (Table 2), with no individual value being greater than 2.0.

Subsequently, positives of flat wax bitemarks were produced and compared with the dental casts (Tables 1 and 3, Column D with Column A). In this second comparison, there was an improvement of the results for the uppers (mean SI = 0.88 mm), whereas for the lowers it was 1.02 mm. While giving lower arch values that were similar, the use of a positive gave improved match values for the upper arch (0.88 *vs* 1.06). This indicates that, wherever possible, a cast of the bitemark should be prepared routinely, if only to give a second, confirmatory assessment of the comparison.

In the third comparison, the wax bites were matched with the reference points marked on the casts and points traced on overlays (Tables 1 and 4, Column C with Column B). The upper arch values revealed a mean SI (1.05) similar to the results above but the lowers revealed a slightly higher mean SI value (1.69) and a maximum value well above 2 (2.72).

Similar results (upper = 1.02; lower = 1.04) were noted in the fourth comparison, when reference points were marked on the positive and compared with points marked on overlays placed on the photographs of the dental casts (Tables 1 and 5, Column E with Column A).

The fifth comparison, reference points, marked on overlay placed on photographs of the positives of the wax bites, were compared with dental casts which had points marked, photographs taken and points traced on overlays (Tables 1 and 6, Column D with Column B). In this matching, excellent results were achieved for the upper (mean SI = 0.79) and lower arches (mean SI = 1.09).

Table 28 Similarity Indices derived from marking reference points directly on the dental cast compared with those derived from marking points on a photograph of the dental cast.

Comparison of a cast marked, photographed and points traced on an overlay with the same cast which is photographed and points marked on an overlay placed on the photograph.		
SUBJECT CODE	Similarity Index (S.I.)	
	UPPER JAW	LOWER JAW
B-S	0.674	0.975
L-K	0.676	0.558
Z-L	1.165	1.552
S-K	0.621	0.692
R-I	0.612	0.729
Mean: **± SEM** **n**	**0.750** **± 0.083** **5**	**0.901** **± 0.176** **5**

The final comparison was of the positives of wax bite impressions and the dental casts of the subjects (Tables 1 and 7, Column E with Column B). In both cases, points were marked, photographs taken and points traced on overlays for comparison. Here too, the results of matching the upper (0.98) and the lower (1.12) arches were excellent.

The results of all the above comparisons are summarised in Table 8.

Interestingly, when a dental cast which had been photographed and then points marked was compared with the same cast when points had been marked directly on to the cast, photographed and points traced on an overlay, it was found that the results were not significantly better than with all the above matchings of bitemarks with dental casts. The mean upper arch SI value was 0.75 mm while the lower was 0.90 mm (Tables 8 and 28). The maximum value for the SI obtained in this series was 1.55.

These data indicate that the best fits are those which give values of approximately 1mm or lower but that all the comparison methods used produced excellent results. It is also clear that matches from photographs are as good as those when the reference points are marked directly on the casts. This finding is of practical importance in that it will obviate any need to mark evidential material directly and thus not compromise any forensic re-examination of such material.

With duplicate determinations (Table 19), each cast was photographed twice (using different films), points were marked on overlays placed on the photographs and then the pairs were compared. As with the matching of the same cast marked either directly or indirectly, this 'paired' comparison would be expected to yield optimal (i.e. the lowest) mean values for the SI with minimum spread of values around the mean. The SI values obtained ranged from 0.50 to 1.03 mm, giving a mean value of around 0.70 for both the upper and lower matchings.

It was then decided to test whether the SI values obtained for the upper and lower self matchings were, in fact, significantly different. The unpaired Student's t-test was employed since this was the statistical comparison of two different (upper and lower) sets of data.

The following probability values from a two-tailed comparison of upper *vs* lower arches were obtained;

Table 2: p = 0.8384
Table 3: p = 0.3721
Table 4: p = 0.1411
Table 5: p = 0.4031
Table 6: p = 0.4046
Table 7: p = 0.7956

It can be seen that the probability, p, is invariably much greater than 0.05, which means that in no case did the upper and lower arch values differ significantly at the 5% confidence level.

Attempts were then made to determine if there is any significant difference between the various self matchings. The paired t-test was employed here to ascertain whether the self matching SI values were not significantly different from each other and therefore could be usefully combined into a single group for subsequent testing statistically against all the non-self SI values similarly combined.

Testing of the self matching data in the following Tables was performed in the following order;

1. Tables 2 & 3: p = 0.4684
2. Tables 2 & 4: p = 0.1105
3. Tables 2 & 5: p = 0.5877
4. Tables 2 & 6: p = 0.399
5. Tables 2 & 7: p = 0.9699
6. Tables 3 & 4: p = 0.0637
7. Tables 3 & 5: p = 0.3892
8. Tables 3 & 6: p = 0.8077
8. Tables 3 & 7: p = 0.7966
9. Tables 4 & 5: p = 0.6241
10. Tables 4 & 6: p = 0.0541
11. Tables 4 & 7: p = 0.4099
12. Tables 5 & 6: p = 0.4094
13. Tables 5 & 7: p = 0.2208
14. Tables 6 & 7: p = 0. 7472

From the above results, it is evident that there is no p value of less than 0.05, which indicates that none of these comparisons yielded any significant differences. Therefore, if we take all the self matchings (i.e. data from Tables 2 to 7 inclusive) as a

Figure 15a and b.

Frequency distribution histograms for Similarity Index values derived from "self" and "non-self" comparisons.

a.

b.

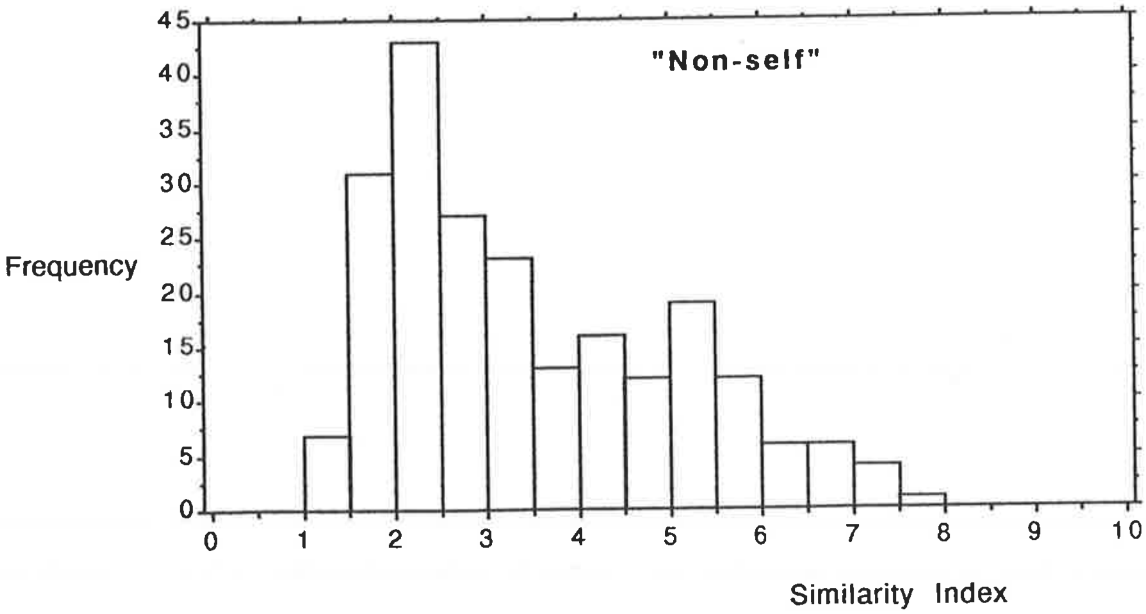
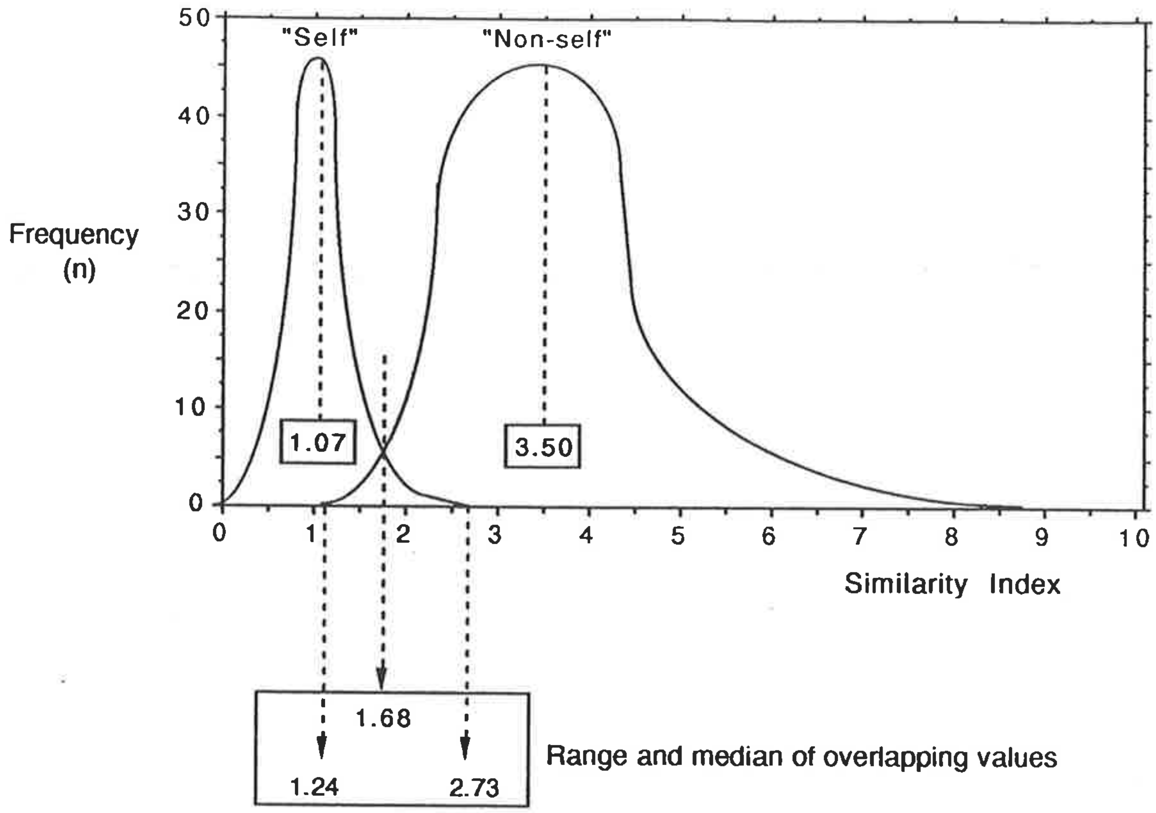


Figure 15c

Smoothed frequency-distribution curves (derived from data in Figs 15a and 15b) showing the maxima, minima and median values of the Similarity Index from "self" (n = 82) and "non-self" (n = 220) comparisons.



'Self' comparisons:

Mean	Std. Dev.	Std. Error	Variance	Coeff. Var.	Count
1.07	0.529	0.058	0.28	49.58	82

Minimum	Maximum	Range	Sum	Sum squared	# Missing
0.389	2.728	2.339	87.52	116.10	318

'Non-self' comparisons:

Mean	Std. Dev.	Std. Error	Variance	Coeff. Var.	Count
3.50	1.575	0.106	2.48	44.996	220

Minimum	Maximum	Range	Sum	Sum squared	# Missing
1.246	7.941	6.695	769.91	3237.40	180

single group, we obtain SI values ranging between 0.39 and 2.73 with an overall mean of 1.07.

The SI values from non-self comparisons (i.e. data from Tables 9 and 10) were then analysed similarly. The data were tested to see if the upper and lower non-self matchings were significantly different. In this case, the unpaired Student's t-test was employed and a probability value of just 0.05 was obtained. Thus, at the 95% confidence level, the upper and lower non-self matchings were borderline but probably not significantly different.

It was further observed that the minimum SI value was 1.25 and the maximum value is 7.94, with an overall mean of 3.50. Therefore, the minimum for the non-self matching group was, in fact, less than the maximum (2.73) of the self matching group, suggesting some degree of overlap of values between the two sets.

Frequency-distribution curves can be plotted for each group (Figure 15a and 15b) and, if it is assumed that the values obtained from both self and non-self comparisons are normally distributed, the point of intersection of the two curves can be mathematically determined (see next page and Figure 15c).

(continued on next page)

The general mathematical formula of the normal distribution is;

$$y = \frac{1}{\sigma\sqrt{2\pi}} . e^{-\frac{1}{2}\left[\frac{x-\mu}{\sigma}\right]^2}$$

If $\overline{x}$ is used as an estimate of μ, and s as an estimate of s, then the approximate point at which the two normally distributed curves cross will be when;

curve y_1 = curve y_2

The point of intersection of the self matching and non-self comparisons was determined. In the self matching tests, which had a sample size (n) of 82, the mean was $\overline{x}_1 = 1.07$ and the standard deviation, $s_1 = 0.529$. The non-self comparisons ($n = 220$) gave

$\overline{x}_2 = 3.50$ and $s_2 = 1.575$.

Therefore;

$$y_1 = \frac{1}{0.529\sqrt{2\pi}} . e^{-\frac{1}{2}\left[\frac{x-1.07}{0.529}\right]^2}$$

and
$$y_2 = \frac{1}{1.575\sqrt{2\pi}} . e^{-\frac{1}{2}\left[\frac{x-3.50}{1.575}\right]^2}$$

but $y_1 = y_2$, therefore;

$$\frac{1}{0.529\sqrt{2\pi}} . e^{-\frac{1}{2}\left[\frac{x-1.07}{0.529}\right]^2} = \frac{1}{1.575\sqrt{2\pi}} . e^{-\frac{1}{2}\left[\frac{x-3.50}{1.575}\right]^2}$$

reducing;

$$3.17\,X^2 - 4.80\,X - 3.05 = 0$$

solving the quadratic equation;

$$X = 7.92 \text{ mm or } 1.68 \text{ mm}$$

The value 7.92 was rejected, as it was close to the maximum value for non-self comparisons and therefore was nowhere near the overlap region of the curves (see Figure 15c). Thus, he value 1.68 mm was accepted as the actual point of intersection of the two curves and this was applied as a "rule of thumb" divider between self and non-self matches. The practical utility of this assumption was tested, as outlined below.

The curves were then transformed to the standard normal curve, where the mean is x and variance is unity, i.e. the area under the curve is 100%. This enabled the calculation of areas under the curve which relate to the probability of obtaining values within particular ranges.

With self matching X =1.067 and S = 0.529, then the Z-score is first calculated.

$$Z_1 = \frac{1.68 - 1.07}{0.529} = 1.153 \approx 1.2$$

The area under the curve is 0.3749 ≈ 0.38.

From the Z-score, it was determined that 12% (i.e. 50% minus 38%) of self matching SIs would be greater than 1.68.

As with non-self comparison where $X = 3.50$ and $S_2 = 1.575$

$$Z_2 = \frac{1.68 - 3.50}{1.575}$$

= -1.16, which gives a probability of p = 0.3770 ≈ 0.38.

In this case, 12% (i.e. 50% minus 38%) of values of non-self comparison fall below 1.68.

The probability of a self matching SI value being less than 1.68 is 88% (i.e. 100% minus 12%), while probability of a non-self match yielding an SI value of less than 1.68 was only 12%. Therefore the chance of an SI value less than 1.68 being 'self' was 88 to 12, or approximately 7 to 1.

Similarly, the probability of a self value being greater than 1.68 is 12% and the probability of a non-self value being greater than 1.68 is 88% (i.e. 100% minus 12%). Therefore, the chance of a value greater than 1.68 being 'non-self' is 88 to 12, or approximately 7 to 1.

If, for example, an experimental SI value of 1.20 is obtained, then;

$$\text{Z-score} = \frac{1.20 - 1.067}{0.529} = 0.25$$

Area under the curve = 0.099 ≈ 10%

In total then, the probability of this value deriving from a self comparison is 50% plus 10% = 60%

On the other hand, the chances of an SI value of 1.20 being 'non-self' can be calculated;

$$\text{Z score} = \frac{1.2 - 3.50}{1.575} = 1.46$$

Area under the curve = 0.4279 ≈ 43%

The chance of this value deriving from a non-self comparison, therefore, is 100% minus 50% minus 43% = 7%.

Thus, the conclusion from our analysis would be that there is a 60 to 7, or an approximately nine to one, chance of a value of 1.20 being derived from a self matching.

Table 29 Comparison of Similarity Indices (S.I.) obtained from self comparisons of experimental bites made on flat and curved (photographed at 90°) dental wax surfaces. The data is taken from Table 2 and Tables 12 to 16.

Figures in parentheses represent the self S.I. from those series where one or more non-self indices were obtained which were, in fact, smaller than the self index. In such cases, an incorrect match would have been concluded in a real forensic analysis. Mean values were calculated with and without these values included.

NAME	Similarity Index			
	UPPER JAW		LOWER JAW	
	Flat wax	Curved wax	Flat wax	Curved wax
B-S	1.140	0.581	0.814	0.816
J-Y	0.816	0.806	0.689	(1.994)
K-U	1.048	(0.898)	0.728	0.709
L-K	0.975	0.951	1.966	1.122
H-S	1.048	(0.781)	1.104	(0.670)
C-N	1.669	0.721	0.818	0.742
W-U	1.133	0.920	0.861	0.734
Z-L	0.875	0.835	0.761	(1.562)
S-K	1.372	0.947	0.876	(0.700)
R-I	0.696	0.721	1.123	(1.344)
A-D	0.880	0.611	1.579	0.661
Mean ± SEM n	**1.059 ± 0.082 11**	**0.788 ± 0.046 9**	**1.029 ± 0.121 11**	**0.797 ± 0.068 6**
	Mean ± SEM n	**0.797 ± 0.039 11**		**1.005 ±0.135 11**

2. The Similarity Index in curved surface comparisons (see Tables 17 and 18).

The results indicate that the best match was obtained when an individual arch of the bitemark was photographed at 90°, the mean SI values for self matches (upper = 0.80; lower = 1.01) being satisfactorily low and approximately twice the corresponding mean values for non-self matches. Although the self and non-self means were significantly different, a 100% successful 'fit' rate was still not achieved.

The other camera angles showed a gradual decline in matching success as the camera angle was decreased. The 75° mean SI values were significantly different but the matching success rate was not impressive.
The lower arch matchings were notably less successful than the upper arches, even with a camera angle of 90°. When both arches are photographed together, the comparisons of the upper or lower arches were just as unsatisfactory as with single arch photographs taken at the 60° and 45°.

These results are in conflict with the findings by Rawson, Vale, Herschaft, Sperber and Dowell (1986) who argued that curvature of the bitten surface does not produce significant distortion. While this may indeed be true for bitemarks with little or no registration of the more posterior teeth, it probably does not pertain when, as in the present study, attempts are made to capture the full arch bite.

One reason for this discrepancy may be that, in the present study, volunteers were instructed to bite with a wide opening of the mouth to produce the experimental bitemark. Even if the full arch is represented in a bitemark, it may therefore not be necessary to include, in the analysis, all reference points, particularly those posterior teeth which may have produced a faint or distorted registration.

It is evident from Table 29 that all the self comparison SI values obtained for curved surfaces are (with one exception) less than the 1.68 dividing line, which means that they are well within the range of values found for the flat wax bites.

3. The analysis of bitemarks in foodstuffs
   (see Tables 21 to 24 and Tables 25 and 26).

a. Apples

Of the eight arch bites investigated, it was not possible to distinguish individual tooth marks in the lower arch bites on the apples by two subjects because the impressions of the teeth were insufficiently detailed. Of the remaining six, it was only possible to make a correct 'self' match with the 'perpetrator' in two instances, one with the upper arch bite of one subject (Table 23) and one for the lower of another (Table 24). Incorrect matches were obtained in the other 4 cases, i.e. a non-perpetrator was most closely matched with the bitemark. Thus, overall, a success rate of only 33% was achieved in bite mark comparisons using apples as the test matrix.

b. Cheese

With this material, it was possible to distinguish the teeth marks for all eight arch bites. A successful match was only possible in 3 instances (38%), in one case for the upper (Table 23) and two cases for the lower (Tables 21 and 24). In the remaining 5 cases (62%), a non-perpetrator was matched (inappropriately) with the bitemark.

c. Chewing gum

It was possible to distinguish the teeth marks for all eight arch bites with this material. A successful match was obtained in 4 cases (50%), two for the upper (Tables 23 and 24) and two for the lower (Tables 21 and 22). In each of the 4 remaining instances (50%), an inappropriate match with the bitemark was concluded.

d. Chocolate-coated confectionery bar

It was not possible to make any useful discrimination of teeth marks in this non-homogeneous material (see Tables 25 and 26) since the bitten edges of the thin chocolate coating crumbled into the softer confectionery basis, which itself was too insubstantial to hold an adequate record of the bite.

From these preliminary results, it was possible to draw some useful guidelines. The consistency of the material must be sufficiently firm yet plastic in order to discriminate the individual teeth marks. For example, a solid (i.e. homogeneous) bar of milk chocolate may well have given better results than the composite chocolate-coated confectionery bar used. This latter had, in fact, been chosen as representative of a very common type of snack which would be expected to offer something of a challenge to a forensic odontologist investigating such a bitemark.

The shearing off of a piece while biting will not leave such an easily noticeable marking in the flesh of the apple as would a simple bite into it. A variety of apple with a less tough skin would be expected to have recorded more detail due to less compression of the apple prior to the teeth puncturing the skin. Better results may well be obtained if a cast of the bitemark were taken to give a positive reproduction of the dentition that produced them, as was done in the study on bites into a wax matrix.

Unfortunately, with no foodstuff tested, was the degree of success in matching the bite to the 'perpetrator' greater than the incidence of inappropriate matches.

It must be noted that the results with foodstuffs, although they do not seem favourable for satisfactory matching, were from bites produced by young adult subjects (dental students) whose anterior teeth were particularly well aligned. Furthermore, the subjects had been instructed to perform only 'normal' bites rather than any controlled 'idealised' bites. It is likely that more convincing results would have been obtained if the subjects had been of different age or had mis-aligned teeth. The main reason, however, is probably that only two to four anterior teeth marks on each arch could be compared, thereby reducing the number of reference points available for comparison.

If the full complement of the anterior teeth had produced sufficient detail on each material, the chances are that the comparison would have been more successful. This again illustrates that a greater degree of success will only be achieved in bitemarks from subjects with symmetrical ('perfect') dentition if a reasonable number (say 8 to 11) of reference points can be discerned on the bitten surface. Obviously, correspondingly lower number of reference points will be needed if the perpetrator's dentition exhibits missing or less well-aligned teeth.

4. Analysis of bitemarks on the skin (see Table 27).

It is evident from Table 27 that the lowest Similarity Index was obtained with the matching of the cast of the 'perpetrator' with the bitemark produced on the skin. The actual value (1.20) is within the range of values obtained when self bites were performed on flat wax specimens and compared.

This is an important demonstration of a bitemark on skin being closely matched to the dentition of the actual "offender" out of twelve "suspects", with the aid of this simple quantitative methodology. This will surely have a major impact on the provision of evidence in courts, especially when there is a need to eliminate other suspects.

We have demonstrated that an effective quantitative comparison, which provides a simple numerical indication of similarity, can now be provided as evidence in courts, thus enabling a more informed evaluation of evidence by the jury.

E. GENERAL DISCUSSION

The unique morphology and alignment of the teeth in the dental arch are functionally and æsthetically very important for an individual. These dental characteristics, when in significant contact with an appropriate substrate, leave prints or impressions displaying the features that have caused them. Peculiar dental features will leave potentially discriminatory marks. If there is a lower frequency of occurrence of a certain feature in the general population, then a bitemark incorporating this feature becomes correspondingly more characteristic of the offender. Thus, unusual characters in a dentition may be more important than the actual number of points of similarity. If inconsistencies can readily be established from these marks, then the 'suspect' can be excluded.

Unfortunately, bitemarks can never be assumed to reproduce accurately the dental condition of the perpetrator. This emphasises the importance of seeking characteristic details, either in the teeth or the dental arch, which may correspond to the marks produced. Furthermore, the process of biting may consist of a combination of incising, sliding, shearing and even squeezing actions on tissues having varying densities and contours, and in foodstuffs of varying fragility and consistency.

Specific dental characteristics that usually are acknowledged are the presence or absence of each tooth, shape of tooth, relationship of upper and lower arch form, mesiodistal dimensions, any irregularity (supernumary teeth, rotations, fractured teeth, diastema, inter-dental distance, etc.). In addition, information on the positional relationship between a criminal and a victim can be acquired by the observation of the bitemark. This becomes important circumstantial evidence which may aid in corroboration of the victim's account of the incident.

Bitemark evidence is becoming increasingly useful in the criminal justice system. Bitemarks left on foodstuffs or skin have led to incriminatory proof against the offender and so the police, prosecutors and defence counsel nowadays realise the significance of bitemarks. Specially-trained experts, who have both the requisite certification and experience, are preferred by the courts for the recognition, examination, interpretation and provision of bitemark evidence.

Bitemarks inflicted on human skin are especially transient in nature and therefore preservation is necessary. Permanent records of bitemarks are primarily obtained by photography and impression-taking. Placement of a scale while taking photographs is very important to obtain life-sized prints and also to indicate the degree of distortion caused by perspective when marks are on curved surfaces. Excision of the bitemark from the cadaver of a victim is sometimes recommended, while bites in foodstuffs can be preserved by simple refrigeration or immersing the object in preservatives.

A method for the forensic investigation of bitemarks based on metrical characters (quantitative assessment) is presented. A basic computer program identifying and measuring the position and extent of the relative deformation of two shapes was refined for employment in this study. After initial evaluation, a mathematical procedure based on the 'least squares' algorithm was chosen for our analyses in preference to the 'robust' method. This produced minimal discrepancies between two determinations of co-ordinates, thereby enabling the calculation of a Similarity Index which would assist in the identification.

This index provided a convenient numerical value which could become recognised in courts as being based on a valid quantitative scientific test. We are confident that the Similarity Index will prove particularly useful when there is a need to eliminate the involvement of some suspects involved in bitemarks.

Comparisons of bitemarks on wax (and their positive reproduction) with casts of the teeth of a 'subject' were made for the purpose of obtaining 'optimum' values for this index. Production of these bites was performed on wax specimens such that distortion-free bites and positives could be made. It must be noted, however, that considerably less biting force is required to produce a recognisable bitemark in wax than in the skin. The reason for this is that the skin absorbs a considerable proportion of the kinetic energy of the bite before sufficient force is generated to produce a visible injury. Human skin also moves when bites are made and all these factors add considerable complications to the analysis of bitemarks on skin.

A systematic sequence for computer recording of the arch shape was developed and was strictly maintained throughout this study. Reference points were chosen, representing the width of individual incisor teeth and the cuspal points of the remaining teeth. It is important to note that, in most bite cases, the width of the tooth marks produced is a function of the horizontal width between the most mesio and disto-incisal parts of the anterior incisors (i.e. the maximum width of the tooth) rather than the length of the incisal edge. With an increased number of reference points, a precise matching of the bitemark with the actual offender becomes a distinct possibility.

The influence of errors due to observer and equipment limitations was assessed. Duplicate determinations were performed to determine if there was any marked observer error in the notation of reference points. This could have occurred while physically marking the points on an overlay and also while recording the points when digitising. It also demonstrates the degree of subjectivity involved during the marking of the points. A significant element of subjectivity also exists in the recording of reference points when aligning the cross hairs of the digitising cursor on the centre of these marked points. Any errors may have resulted from inconsistencies in the setting up of the various items of recording equipment (e.g. camera, enlarger) were also assessed in these experiments.

An extensive literature review has shown the steady introduction of various technological advancements in the examination, interpretation and exhibition of bitemark evidence within the limits of the legal system. It is evident, however, that most of these advances relate to associative or qualitative comparisons. Relatively few papers are concerned with quantitative evaluation of such comparisons.

The quality of presentation in court of what has been observed and the adequacy of supporting documentation, has always been fraught with difficulties. It is therefore important to record all observations together with photographs as added documentary evidence for the courts. If any abrasions or lacerations are involved, we recommend recording the marks by impression-taking.

The old adage that "photographs don't lie" can, however, be both true and false. Our own experience in investigating bitemark cases has shown that what is observed with the eye and what is produced on photographic prints may reveal subtle differences. This could be due to the problems of colour sensitivity of the film or paper and also the optical limitations of the camera equipment.

Needless to say, however flamboyant or rhetorical an expert witness might wish to be, simplicity in presentation of evidence to the court is crucial. The jargon-laden presentation of over-complicated evidence may serve only to confuse the jurors who have, of course, been selected from the lay community. The method that we have developed is based on a quantitative evaluation which allows the presentation of a simple numerical index which should lead to easier appreciation of the relevance of the evidence in the court.

One disadvantage of this study was the inability to make three-dimensional measurements which would have contributed significantly to the comprehensiveness of the identification. Only linear measurements are involved in the present study. Nonetheless, the positioning of the co-ordinates for the linear measurements should provide sufficient indirect indication of any angular relationships of the teeth.

Each dental arch (bitemark and cast) was characterised by the co-ordinates of reference points located within a Cartesian system of orthogonal x and y axes. The results of this study have shown that 'self-matching' of wax bites and positives (even when the points were marked directly on the cast) of the dentition that produced the marks does not reveal any marked differences in the resultant Similarity Index.

Therefore, whether a photographic print of the bitemark or the positive reproduction of the dentition producing it is provided, comparisons will reveal a valid numerical index provided, of course, that the actual marks are sufficiently detailed.

We have shown that, using the interactive graphics program, a bitemark can be classed as a reasonable fit with the teeth of the offender when the value of the Similarity Index is below 1.68.

The results obtained from the comparison of the foodstuffs were not very encouraging. This is primarily due to insufficient number of teeth recording indentations on the bitten material. Sometimes, it was only possible to discriminate indentations from two teeth. Further, any shrivelling or disintegration of the food material with time will reduce the accuracy of determining width of the individual teeth. The physical nature of the foodstuff has a marked effect on the adequacy of a bitemark investigation, with the best results being obtained from the more homogeneous and plastic foods.

With human skin as the test substrate, we found that it was possible to obtain an index which is well within the range of values obtained with the control comparisons. The matching of a bite on the skin proved to give, overall, the best match with the perpetrator's teeth, because of the greater number of recognisable reference points compared with bites in foodstuffs. Although this was an experimental study, its usefulness with skin bites in real forensic situations is emphasised.

This study has developed a new scientific method that will, it is hoped, play a significant rôle in future bitemark investigations. As this method involves a quantitative comparison, the simple numerical indices which result will be far easier to interpret when produced as evidence in courts of law.

This program can also be used for archival recording of the dental arch characteristics of workers, especially those in high risk occupations. Such dental records would be valuable in providing a definite forensic identification, should it ever be necessary.

Further research is necessary to develop a system for describing and recording the shape of the labial surfaces of the anterior teeth. This will enable better determination of a match in situations where a shearing or sliding bite is involved and only the labial curvature of the teeth is registered in the foodstuff.

Studies should also be undertaken of cases where bruising is associated with bitemarks, so that the area of spread of the bruise can be statistically analysed and related to the dentition that produced them. It is hoped that the study of the manner of spreading will lead to the provision of a reliable index of the time interval between the production and the examination of a bitemark.

F. APPENDICES

APPENDIX 1

THE PHYSICAL APPEARANCE OF BITEMARK INJURIES.

A wound has been defined as a disruption in the continuity of any of the tissues of the body by injury. It is thus apparent from a legal point of view that even a single scratch or abrasion may be just as important as more dramatic injuries. At the same time, a bruise which does not necessarily involve loss of continuity of the overlying skin may not be legally agreed to be a wound (Cameron, 1976). A bruise, however, does involve a loss of continuity in the underlying tissue with damage to blood vessels.

a. Classification of injuries (Cameron, 1976).

Bitemarks are skin injuries which may be either two- or three- dimensional and manifest as follows;

(i) Abrasions:

Abrasions are caused by injury to the superficial layers of the skin. Their appearance may give clues as to the mode of production. Abrasions may be subdivided into;

Scratches. These are narrow linear abrasions due to a sharp object passing across the skin, moving the surface layers in front of it and causing the skin to "heap up", thus giving an indication of the direction of motion of the object.

Grazes. These are variations of scratches in which a rough object comes in contact with a wider surface of skin. The detailed appearance will vary with the circumstances, being coarser with a rougher implement and fine with an object that has a smoother surface.

Impression or impact abrasion. This is caused by the application of an object to the surface of skin imparting the pattern of its shape to the skin.

(ii) Contusions (bruises):

These involve rupture of subcutaneous blood vessels allowing the extravasation of blood into the surrounding tissues.

(iii) Lacerations (ruptures):

A laceration is a tearing of the skin and subcutaneous tissue. An examination of lacerations may identify the agent which has caused them. Lacerations are broadly classified into two categories;

Incised wounds (cut, slash, slice).
These wounds may be caused by an object with an edge (linear or curved).

Penetrating wounds (stab, puncture, perforation).
These involve penetration through the skin into the underlying tissues and have, as opposed to incised wounds, a depth greater than their surface width or breadth and may be produced in some animal bites.

The patterns of marks produced by the different types of teeth have been decribed by Levine (1982). According to him, the pattern of injury seen in bitemarks generally reflects the basic shape of the incisal or occlusal area of the type of tooth in question. Most often in the adult dentition, incisors leave rectangular marks whereas linear markings are common with recently erupted incisors. Canine teeth usually cause triangular markings with the apex towards the labial and the base towards the lingual of the arch. In the case of premolars, they cause single or dual triangles with the bases of the triangles facing or sometimes coming together to form a diamond shape. These marks are, of course, not perfect geometric patterns but only approximations.

b. Classification of bite types.

Rawson (1986) listed five basic types of bite;

(i) Type 1: Incised or "weapon" marks without discolouration. This type of mark may represent a post-mortem bite, because of the lack of bleeding into the underlying tissues, or it may represent a bite made with enough force to leave impressions or three-dimensional features but with insufficient force to rupture underlying vessels. The term "incised" in this context does not necessarily indicate any actual break to the surface of the skin but merely an impression into the skin. This type of bitemark often fades quickly but may produce bruising with time.

(ii) Type 2: Incised marks with bruising. These are the more common marks produced where sufficient force was used to rupture vessels and cause bleeding below the skin. They may be more sharp in outline immediately after the bite and often change character with time, ultimately becoming more diffuse.

(iii) Type 3: Multiple marks or those bites that demonstrate drag marks. These marks often are complex and are the most confusing bitemarks to identify. The basic pattern of arch form or individual tooth marks may be observed around the border of the injury. The pulling or sliding of the teeth over the tissue causes bruising but not removal of tissue in pieces.

(iv) Type 4: Suction marks. These marks, often known as "love bites" or "hickeys", are characterised by tooth marks produced around an area of bruising (see Figure 1).

(v) Type 5: Avulsion marks. These occur as a result of a particularly vicious bite in that tissue has been completely removed. Body parts may be lost such as a finger, tip of the nose, ear, nipple or penis. The edges are often ragged but present important evidence to be recorded.

3. Observation of the tissue changes produced by bites.

It is well established that bitemarks produced in skin and the reaction of the surrounding tissues of the victim may indicate the identity of the agent producing them the offender and also the probable time of infliction of the injury.

Sebata (1963) made significant observations on living persons upon whom experimental bites had been inflicted. Every tooth mark was clearly impressed in the skin as a depression immediately after the bite pressure. The stronger the bite pressure, the clearer were the forms of the cutting edges of the incisors produced, whereas sucking with force caused impression of the labio-lingual surfaces of the teeth on the skin. As time elapsed, physiological responses caused the affected tissues to swell. In 10 to 15 minutes, the area surrounding the tooth depressions began to swell. The actual depressions began to swell about 20 minutes after the application of the bite pressure and the previously discrete individual tooth marks became a single line due to this swelling.

Subcutaneous bleeding caused by bite pressure appeared pink or red in the form of each toothmark, while that caused by suction appeared as numerous red spots filling the whole sucked zone. With the elapse of time, the bleeding spread diffusely and became an extensive bruise. This subcutaneous bleeding seemed to occur in proportion to the amount of force applied in sucking. In all cases, swelling remained up to 5 hours after reaching a maximum from 20 minutes to 1 hour after the biting. The swelling subsequently diminished as time passed. The tooth marks gradually resumed their individual forms and by 24 hours when swelling had completely disappeared, hæmorrhagic areas in the tooth marks and the sucked zone were evident.

From 24 hours or more after the biting, a new bruise, which did not appear directly after the bite process, began to appear and remained for a long time. This was taken to be a hæmorrhagic infiltration or a kind of angioma and its colour was different and its resolution slow. Victims in which this change occurred usually experienced severe pain prior to its occurrence. Subcutaneous bleeding in tooth marks maintained the shape of the cutting edge of each tooth for approximately 72 hours in the subject having little hypodermic fat, while such tooth marks in the subject having much subcutaneous fat disappeared early (24 to 28 hours).

Sebata concluded from these experimental bitemark studies that:

(i) The size of the dental arch of the 'offender' and the arch mark differed slightly. The differences varied from +10% to -30% in the length but were within ± 5% in the width.

(ii) When a high degree of sucking had been involved with the biting, the width of the arch mark increased, while its length showed no change.

(iii) The changes in measurement varied according to the constitution of the subject and the region of the body. In the person or the region having much subcutaneous fat, the change in the width was increased and that in the length decreased, while those with little subcutaneous fat showed the reverse.

APPENDIX 2

PSYCHOLOGICAL ANALYSIS OF PERPETRATORS OF AGGRESSIVE BITEMARKS.

Walter (1984) has presented a comprehensive analysis of the psychological factors which appear to be relevant to perpetrators of aggressive bitemarks. The main features of this analysis are paraphrased below.

Biting is a highly personalized psychological indicator of the perpetrator's crime style or motivational intent. Suckling marks, abrasion and avulsion of tissues are all important factors in identifying the physiological and psychological characteristics of the biter. Walter studied the status of the perpetrators of the various type of bitemarks and derived three major motivational categories;

a. Anger impulsive biting.

Consistent with over-aggressive and uncontrolled displays of impulsive anger, this type of biter is incompetent in dealing effectively with conflicting situations. Particularly, when the biter loses self-control, there will be a quick administration of a bite which is governed by time, location, situation and form of anger. This is exhibited by children who will compulsively inflict injury to express rage, hurt, fear and jealousy towards the bitten person.

In the case of a child-abusing parent, the bitemark inflicted on the child can arise from internal conflicts and emotional reaction to the parenting responsibility. Whether emotionally overloaded by internal demands, competetiveness, jealousy, frustration, or ineptitude, the assaulting parent suspends the caring and nurturing contact with the child and reactively victimizes it by painful biting, especially in sites where the child best responds to reassuring tenderness. Other adult assailants use biting to dominate, subjugate, terrorize, humiliate or even possibly warn the victim.

b. Sadistic biting.

The sadist will often develop through the following personality types: inadequate personality; obsessive-compulsive personality; anti-social personality; passive aggressive personality; and sociopathic (psychopathic) sadism. These aggressors display a protracted and ritualistic biting of the victim to satisfy their increasing lust for domination, control, omniscience and to satiate sexual demands in the 'pain continuum' rather than the 'coital climax continuum'.

c. Ego-cannibalistic biting.

Undoubtedly, the most vicious and destructive type of biting is perpetrated by persons whose behaviour lies within this category. The ego-cannibalistic biter may just be an over-developed sadist or an ego-maniacal person who develops the desire to inflict pain and kill his victim. The bitemarks in this type of case would most probably show a significant amount of tearing, sucking and avulsion of the flesh of the body .

APPENDIX 3

PROCEDURES AND TECHNIQUES FOR INVESTIGATION OF BITEMARKS.

The use of bitemark evidence in the criminal justice system and the resultant publicity associated with it has caused an awareness of the need for the proper recognition, investigation, preservation and comparisons of bitemarks. Realising this importance, the American Academy of Forensic Sciences, in 1980, requested the American Board of Forensic Odontology to develop standardised procedures for bitemark analysis. The guidelines developed are useful in the analysis of bitemarks to improve the quality of the investigation and conclusions therefrom.

Greater emphasis of current research in forensic odontology is directed towards refining available methods of identification and gathering more useful information associated with bitemark evidence. It is important to realize that there exists no single method which can be utilized in all bitemark studies. The method used by any particular investigator will depend upon personal preferences and the ability to handle or accommodate a particular technique. Various techniques and procedures have been employed by researchers in recognising and analysing bitemarks. Some of the techniques, however, are not acceptable for presentation in certain countries. Some of the methods employed are outlined below:

a. Direct archform comparison.

If the bitemark itself has been preserved and replicated, or if the bitemark has been made in a foodstuff and its form preserved in a permanent material, it may be possible to demonstrate directly the concordance between a particular dentition and a bitemark. The model of the dentition of the suspect can be placed directly into a replica of the bite or into the preserved material. This technique has been employed by Kerr (1977) in the case of a bite into an apple, and Simon, Jordan and Pforte (1974) in a case involving a bite into a sandwich.

b. Direct photographic comparison.

Direct comparison of the bitemark in a photograph with a plaster cast of the dentition of a suspect is one of the simplest means of comparison. Care must be taken that the photograph of the bitemark is at exactly life size and there should be a scale included in each photograph and/or transparency to indicate this. The general criticism of this technique is the obscuring of the points of concordance while making the actual comparison. Direct comparison of the cast of the teeth of the subject with a positive reproduction of the bitemark is another useful method of comparison. This technique is especially useful when the third dimension (depth) is present in the bitemark and it is reproducible.

c. Transparent overlays.

Luntz and Luntz (1973) described the technique of placing clear acetate film directly in contact with the pressure-inducing incisal and cuspal surfaces of the suspect's casts and then outlining the bite pattern with ink. This technique is more easily accomplished if the incisal edges on the cast are highlighted by ink or graphite from a pencil. Subsequently, the acetate film is used for superimposition upon the available bitemark photograph. Bernstein (1983) has recommended that the tracing be done by placing the acetate directly over a life-sized incisal view photograph of the study models on which the incisal edges have been highlighted by inking. Some experts on the other hand, prefer to mark the areas of infliction observed on the photograph on to an acetate film first and then compare these tracings with the incisal edges of the teeth of the suspect.

Each of the techniques which involves marking or tracing the bitemark is open to criticism in that there may be a degree of subjectivity when producing the outline detail of the bite form.

Luntz and Luntz (1973) described the use of 'onion skin' (a translucent paper) and carbon paper placed together over a short section of pliable tubing. The carbon was on the outside of the 'onion skin' and the models of the teeth of the subject were then closed tightly in a biting action over the carbon paper. Each tooth contact then produced a black mark on the 'onion skin' which could be compared with the bitemark photograph.

Drinnan and Melton (1985) used the technique of pressing a model from the suspect directly into thin acetate film placed on human skin (in the same area as the victim's bitemark) in an attempt to simulate the particular circumstances of the original bite.

The indentations made in the acetate film were then outlined with Indian ink. A three-dimensional record can also be produced by gently pressing "Nescofilm" or "Parafilm" (deformable film made from a polyethylene and paraffin wax composite) against the occlusal surfaces of the teeth on the cast of the suspect.

d. Use of slide and overhead projection.

One technique advocated for courtroom display is to project a slide transparency of the bitemark on to a screen and then use another projector or an overhead projector to superimpose the suspect's bitemark. This technique is really little more than another type of overlay method but it does give the benefit of providing a greatly enlarged image for the court to visualize and may assist the jury to appreciate the evidence of the forensic odontologist. This technique would probably satisfy the call by Berndt (1982) for "artful persuasion" of juries.

e. Enlarged photographs of bitemark and suspect's bite.

Some forensic dentists prefer to demonstrate points of concordance by presenting greatly enlarged photographic prints of the bitemark and the suspect's bite pattern side by side. These exemplars may be produced in a variety of ways; a photograph of a bite produced in wax directly from the suspects casts; a photograph of the incisal edges; or even a photograph of a bite produced in a volunteer's skin using the suspect's dental model. Individual features of each tooth impression can be identified on each print alternately.

e. Computerised electronic image enhancement.

A rather more sophisticated technique for demonstrating concordance of bitemarks depends upon the use of the computer. A digitised image of the bitemark can be stored in the computer, can possibly be enhanced and made clearer and then manipulated around the screen to be compared with another bitemark image which is visualized on the screen simultaneously (Beckstead, Rawson & Giles, 1979).

The computerised technique further allows density slicing, edge enhancement, three-dimensional display and spatial measurements. The process of density slicing, makes it easier to distinguish changes in density and areas of equal density from a transparency or photograph that is being analyzed. Varying shades of grey (the "grey scale"), therefore, can be interpreted more accurately. The grey scale is extremely important because the human eye and brain have difficulty seeing and comprehending what is in this area of the spectrum; hence, a portion or all of the pattern of injury may be overlooked, unrecognised or wrongly evaluated. The computer system can render the grey scale more obvious to the human eye by substitution with colours whereby differences can be highlighted by colour assessment.

By placing a photographic transparency on a light table and focussing a video-camera on it, it is possible to break down the video image into levels of density to be displayed on the monitor, presented either in negative or positive models and in colour.

Another technique that is helpful in analysis is edge enhancement. This technique displays the borders of a bitemark and the depth of bitemarks as white and black interfaces. The main purpose of the technique is to maximise only those areas of changes in density. Therefore only the areas of sharp contrast are enhanced, not the neutral lines. By this technique certain lines, hidden discrepancies, scratches and perforations can be displayed for a more detailed investigative analysis.

The three-dimensional capabilities of this particular technology are interesting. The technique takes a normal two-dimensional image and shows the third dimension. The third dimension is a variation in density, from either the depth of tooth marks or as an indication of hæmorrhage. This is then transposed as either a convexity or a concavity on the display screen. It must be emphasised, however, that this 'dimension' cannot be accurately portrayed, i.e. metric analysis is virtually impossible.

Another interesting capability of the computer system is spatial measurement. A linear measurement of any particular area or sector can be useful in analysis of a bitemark.

Importantly, the use of computerised analysis allows any examination to be repeated by others to verify the interpretation. of the initial investigators. The sophisticated digital analysis also gives the investigator the capability of superimposition. By this technique, images can be analysed separately, collectively or by superimposition to accomplish effective scrutiny of the image recorded.

g. The use of videotape to demonstrate the dynamics of bitemarks.

The use of video-tape display in the courtroom has been accepted in several states of the U.S.A. (Beckstead, Rawson & Giles,1979; Standish, 1984), and it may well be that more sophisticated computerised techniques of bitemark comparison could be video-taped and edited appropriately for visual presentation in the courtroom. It should be noted here that any editing must be within the bounds of scientific integrity and legal criteria for acceptance in court.

Historically, still photography has been used to record static bitemark impressions on relatively flat skin areas. This technique allows accurate comparison with a dental model for identification and presentation as evidence. The forensic odontologist however, seldom encounters this ideal combination when working with a traumatic bitemark. The more usual occurrence is a bitemark that abrades or lacerates the skin along a curved surface.

By using the video recording technique, the forensic odontologist is able to show the interaction using a dental model on the skin or a bitemark. This will demonstrate clearly recreation of events for evidentiary comparison and presentation, not only static but also the dynamic movement which has taken place. Further, the image of the teeth can be 'dissolved' and 'resolved' over the tooth mark in an attempt to visualize the degree of similarity (West & Frair, 1989).

Beckstead, Rawson and Giles (1979) showed that images can be focussed on a photographic print, models, simulated bites and other evidence. Here photography and video-taping of the evidence made perpendicular to the skin surface are absolutely necessary. The lighting in the studio is extremely important to bring out the highlights and the enhancement of the edge of the bitemark. The special-effects generator superimposes one image on another on a monitor or video screen for viewing and analysis.

h. Computerised axial tomography (CAT scanning) techniques.

In a case study presented by Farrel, Rawson, Steffans and Stephens (1987), plaster models of the dentition of the suspects were placed in the head holder of the General Electric Model 9800 computerised axial tomographic (CAT) scanner. The teeth were oriented as if each suspect was in the supine position lying with the head in the gantry opening of the CAT scanner.

Laser alignment beams inherent to the 9800 system were used to centre the teeth in the gantry. Both horizontal and vertical alignment were obtained using specific points on the teeth. The vertical laser was directed through the mid-line of the mandible and maxillary central incisor, while the horizontal laser was allowed to just touch the incisal edges of the cuspids. Hard copy transparencies using magnification factors to produce 'one-to-one' images were produced, using the special CT/T camera designed for the CAT scanner.

These CAT scans of models produced precise registration on transparencies that allowed determination of which dentition produced the bitemarks. The precision was then verified by direct overlay and direct measurement of the bitemark (even on photographs). The precise nature of the registrations allows confidence in a determination of degree of match when there is a high degree of correlation between teeth and wound pattern. The advantages of the CAT method are, unfortunately, largely outweighed by the difficulty of access of the forensic odontologist to such rare and expensive machines.

i. The identifications of bitemarks using the reflex microscope.

With many of the methods currently used to record and observe bitemarks, it is often not possible to meet all the analytical requirements necessary to achieve identification and still retain the original evidence. An important feature of the reflex microscope is its ability to make accurate, non-contact, three-dimensional measurements of the surface of any material. This is achieved without having to take impressions or direct measurements, even on such substances as butter. In this instrument, the optical image is measured in both horizontal dimensions by tracing a crosshair, fitted in the eyepiece, over the image. The third dimension is determined by measuring the depth of field of the image.

This instrument was used by Ligthelm, Goetzee and Van Niekerk (1987) to determine the alignment, physical characteristics and three-dimensional assessment of bitemarks. The *x-y-z* coordinates of selected points observed with the reflex microscope were converted into electronic signals and recorded on an IBM-XT computer with programmes specifically designed to process them. To be able to match the bitemarks and the cast of the dentition, the *x-y-z* coordinates of the bitemark profile were transformed mathematically with the computer programmes to produce a positive contour profile of the bitemark. This positive image was then visually compared with the profile of the dentition cast.

Computerised three-dimensional comparison between bitemarks and the dentition of suspects proved to be feasible and very successful. Multiple measurement could be carried out and stored electronically for later use. This technique is simple and it is possible to retain the bitemark in its undamaged state.

j. Analysis of teeth marks with stereometric reproduction:

This technique, also is non-destructive and employs three-dimensional plotting which seems to meet the essential requirements for a comparison between teeth marks found and teeth marks produced by a suspected individual. Frykholm, Wictorin and Torlegard (1970) considered it to be a reliable analytical method. They prepared a positive reproduction of the bitemark with hard plaster for analysis and carried out the plotting using a photogrammetrical stereoscopic instrument, the Wild "Autograph A7". Reference points from these plottings were connected by straight lines, thereby forming closed polygons. The length of the sides of the polygons and the angles between them were measured and values expressed numerically for comparison. It was recommended that plottings, which are extremely time-consuming, should be made by an investigator who is thoroughly familiar with both the application and the technique and who also has a well-developed visual stereoscopic ability.

The authors concluded that their method enables the resemblance between toothmarks and tooth cast to be expressed numerically, making comparisons more objective and thus avoiding subjective bias.

k. Scanning electron microscopy in the analysis of bitten objects.

The relatively great depth of focus of the scanning electron microscope (SEM), combined with its high magnification of surface structures, makes this instrument useful for the study of the fine structure of curved surfaces. In many bitemark cases, macroscopic or stereoscopic examination may be sufficient but an SEM examination might add valuable information to the investigation. Under SEM, the incisal edges of the tooth casts may reveal enamel defects or exposed dentine, probably resulting from micro-fractures. This technique discloses a great number of individual characteristics which are not visible in the ordinary microscope or stereomicroscope (Solheim & Leidal, 1975).

One potential drawback of this technique is that the SEM can only be used on specimens which have been given a vacuum-deposited metal coating and this process can cause destruction of the bitten object. Bang (1976) used a conductive film of gold, approximately 300 to 400 Å (30 to 40 nm), for this purpose. In practice, this time-consuming procedure can be employed only on those relatively few foodstuffs which are capable withstanding the procedure and of demonstrating fine details. It cannot be employed in ordinary scratch marks because such simple linear markings leave a record with insufficient detail.

l. Dusting and lifting the bite print

According to Rao and Souviron (1984) who developed this method, one only requires standard black fingerprint powder and a camel hair paintbrush. A very small amount of powder is placed on the brush and the bitemark on the skin is very lightly brushed. The spacing between the arches should however be spared so that the details will not be obscured by excess powder. Photography before, during and after brushing aids the documentation and preservation of this evidence. Clear fingerprinting tape is used to lift the bite print. The lifted print is then placed on a glossy fingerprint card which can then be placed in the case file as part of the record to be used at a later date as evidence in court.

The jury will then be able to handle this card as they do a photograph in a particular case. Comparison can then be made using this bite print lifted from the victim and that prepared from the marks made using the dental cast of the suspect's teeth on a living person or a cadaver.

m. Trans-illumination of bitemarks.

Trans-illumination is a simple and effective method, described by Dorion (1986), for determining if a bitemark on skin was produced antemortem, perimortem or postmortem. While the process of trans-illumination *per se* is non-destructive to the bite mark evidence, it is usually necessary to excise the region containing the bite. Trans-illumination is of value with a deceased person but is obviously inappropriate for bites on the skin of living victims.

The excised specimen, with its underlying muscle tissue removed, is mounted on a clear glass plate which rests on top of a light box. Light is transmitted through the specimen and its intensity is varied by means of a rheostat. Pieces of black cardboard form a mask to limit the light to the specimen area only.

Through the study of the subcutaneous haemorrhage by trans-illumination, additional information regarding the perpetrator's dentition may be derived. With trans-illumination, one can view through the epidermis, dermis, the connective and adipose tissues. An absence of subcutaneous hæmorrhage could mean that there was insufficient pressure inflicted by the perpetrator of the bitemark or that the bitemark was inflicted after death.

Dorion claims that trans-illumination can provide information which under normal circumstances, would not be easily identifiable. Such a case could include the observation of the presence of a tattoo on a badly decomposed body. Current techniques of trans-illumination of the tissue with subsequent intensification of the image can produce sharp images of the damage to tissue caused by biting forces. The skin sample carrying a bitemark can be carefully sutured to a retaining ring before excision and, with careful treatment, can be presented for trans-illumination photography.

n. Radiography of bitemarks enhanced with contrast media.

Radiography has been used as a diagnostic and interpretive instrument for many years. Recent work by Rawson, Bell and Kinard (1979) has expanded the experimental use of radiography to include the examination of bitemarks or other patterned injuries.

This radiographic procedure depends on contrast enhancement of the bitemark. A 0.25 mm thick layer (no mention was made in the methodology of how this might be controlled) of 60% iodine solution was used as a radio-opaque medium to cover the bitemark. Standard radiographic techniques were then employed for soft tissue visualization. A diagnostic X-ray machine was used to produce xero-radiographs of the specimen. The xero-radiographs were processed in the negative and positive mode for comparison. The impressions left by incisal tooth edges could be accurately compared with the dentition producing the original bite.

o. Rapid comparison of bitemarks by xerography.

McCullough (1983) described a technique in which photocopies of both the original cheese and the 'clay bite' impressions of a suspect's dentiton were made on a xerographic copier by separately placing both items on the glass platen, bitemarks downwards. By experimenting with different setting of the dark/light contrast control, good copies of both sets of bitemarks were obtained. When the paper copy of the marks in clay was judged to be of sufficiently good contrast and definition, a "Mylar" (polyethylene terephthalate) transparency copy could be made directly from it. This transparency was then used as an overlay on the paper image of the cheese. The identity of the teeth marks was then assesed.

This technique offers the advantage of determining in a matter of minutes whether there is a high probability of identity between the evidence and known bitemarks.

p. Ultraviolet photography

In the United States, photography has been used as evidence since the case of Luco *v.* United States in 1859, when it was used to prove forgery (Sansone 1977, quoted by Frair & West, 1989). In addition to its traditional uses, conventional photography and ultraviolet (UV) photography have been used to record evidence in bitemark identification and to produce convictions in assaults, rapes, murders and child abuse cases.

Conventional photography uses ordinary films and light within the visible spectrum to give a reproduction similar to that which the eye sees, whereas UV photography requires the use of specialized filters and light sources in the recording of images which are invisible to the eye.

Naturally, evidence can deteriorate with the passage of time. Bitemarks begin to discolour, distort and become obscured by bruising soon after the wounding occurs. Since the human eye is sensitive to only a small portion of the electromagnetic spectrum of energy, much evidence is invisible to normal sight. This can be recorded with special photographic techniques using infrared-sensitive or UV-sensitive film emulsions with appropriate light sources. Just as objects selectively reflect and absorb visible light (wavelength 400 to 700 nm), they also absorb and reflect light in the invisible ultraviolet (200 to 400 nm) and infrared (700 to 1200 nm) spectra.

Short-wavelength (200 to 300 nm) UV radiation records almost entirely the surface artifacts, while some experts claim that long wavelength (300 to 400 nm) UV penetrates to a depth of 2 to 3 mm into the skin (Kikuchi,1983, quoted by Frair & West, 1989). In a recent study however, it was estimated that long UV radiation penetrates the fair Caucasian skin to a depth of only 6 to 90 micrometers (Krauss, 1989). With the penetration of UV limited to the epidermal layer of skin, it is thus possible to record conditions within the epidermis, eliminating the optical influence of the dermis and subcutaneous layer (for a description of the anatomy of the skin, see Appendix 4).

Normally, melanin pigment is only found in the epidermal layer of the skin, particularly in the basal cell layer. Melanin absorbs UV radiation and provides natural protection against sunburn. The spectral wavelengths that melanin absorbs (650 to 700 nm and 330 to 400 nm) are not greatly absorbed by other epidermal chromophores such as hæmoglobin or oxyhæmoglobin. Injury to the skin causes melanin to be released, spreading it throughout the area. With healing, special cells (melanocytes) gather up melanin and appear to migrate to the edges of the wound providing opportunity to record photographically the outline of the tissue injury pattern. With an increase of melanin at the injury site, there is more absorption and less reflection of long wave UV than the surrounding area, making possible detection of changes by reflective UV photography (Kraus & Warlen, 1984). This epidermal response has been observed as early as three weeks and as late as three months after the injury (Krauss, 1989).

In the experimental study of West, Billing and Frair (1987), a bitemark pattern began to appear in the UV photographs on the seventeenth day. The intensity and clarity of the bitemark increased, peaked at 60 days and then decreased. It must be emphasised that the bruising had faded on the twelfth day, so no marks were visible under ordinary light. In another test, the abraded skin of Caucasians absorbed UV radiation,while in Negroes the non-production of a differentiated pigmented area (melanin) in abrasions and lacerations provided no image of the bitemark outline.

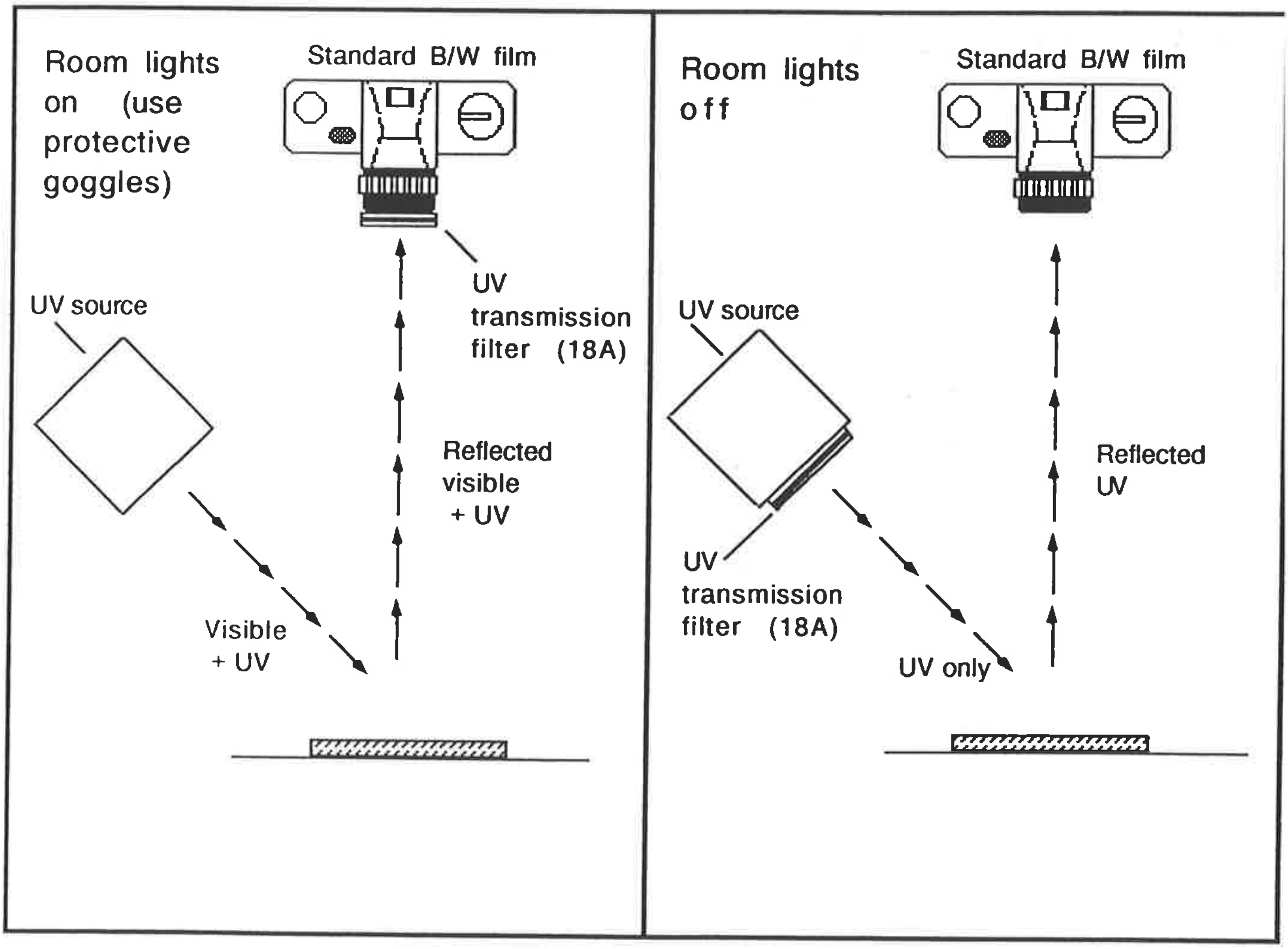
Ultraviolet photography, for forensic investigations, can be divided into three distinct areas;

(i) Fluorescent UV photography:

This utilizes long wavelength UV radiation to cause certain materials to become excited and visibly fluorescent. Fluorescent UV photographs can be made with either conventional colour or black and white film. The technique employs a long wave length UV light source and a UV-absorbing filter over the lens of the camera for UV photography. The filter absorbs all UV radiation reflected from the subject and allows the photographic recording of only the other wavelengths emitted by the

Figure 16

Diagrams illustrating the technique of long-wavelength UV photography.



fluorescent material. Through the use of fluorescent UV photography, an investigator may also detect and record body fluid stains.

(ii) Reflective long wavelength UV photography (see Figure 16).

A primary problem in this technique is that the subject matter being photographed cannot be viewed and the wavelenth of the energy source illuminating the subject is outside the range of human vision (thus invisible). The results are visible only after the film is processed and printed.

The technique uses a light source which emits wavelengths shorter than 400 nm and a film emulsion sensitive to this portion of the electromagnetic spectrum. Generally, the shorter the wavelength of energy, the less penetration of that energy into the subject. Reflective long wavelength UV photography can be applied to effectively 'remove' the image of tattoos which may mask evidence. Since UV does not penetrate deeply into the tissue, the pigment which makes up the tattoo is located deeper than the penetration of the UV and thus the image of the tattoo is eliminated or reduced using this technique. The visible light is however eliminated photographically by using a barrier filter such as the Kodak Wratten Ultraviolet Filter No.18A/Glass. This does allow some infrared to pass through.

With the limited practical use of colour UV in medical forensic photography, black and white reflective photography is preferred.

(iii) Short-wavelength UV photography

Short-wavelength UV has the advantage of recording only surface artifacts or disturbances, e.g. fingerprints. However, special quartz lenses are required for this technique and the operator's eyes should be protected.

APPENDIX 4

THE ANATOMY OF THE SKIN (see Figure 17).

(condensed from "A Textbook of Histology", edited by Bloom and Fawcett,1975).

The colour of the human skin may vary due to;

a. the inherent colour of the skin (yellow, due to carotene) and modified by the presence of the melanin pigment,

b. colour of blood seen through the skin, i.e. the amounts of capillary blood

and c. the varying pigmentation of the skin, by virtue of race, geographical environment, sex, age, constitution and condition of health.

The skin is one of the largest of the organs, making up some 16% of the body weight. Its functions are several. It protects the organism, excretes various substances and is an important element in thermoregulation and maintenance of water balance.

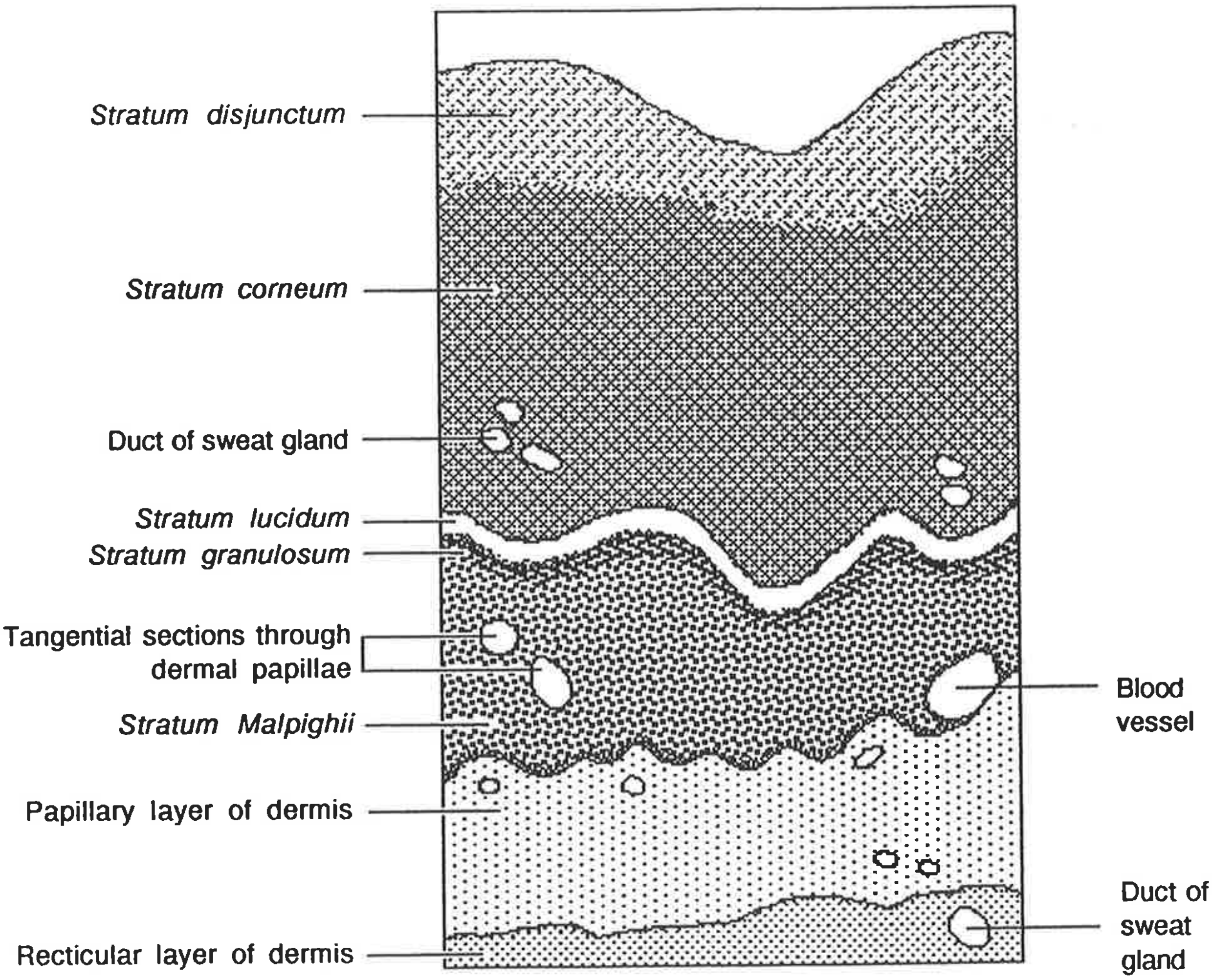
The skin covers the surface of the body and consists of two main layers, the surface epithelium, the epidermis, and the subjacent connective tissue layer, the dermis or corium. Beneath the dermis is a looser connective tissue layer, the superficial fascia, or hypodermis, which in many places is largely transformed into subcutaneous adipose tissue (or *pannicilus adiposus).* The hypodermis is loosely connected to underlying deep fascia, aponeurosis, or periosteum. The skin is continuous with several mucous membranes at muco-cutaneous junctions. Such junctions are found at the lips, nares, eyelids, vulva, prepuce and anus.

The skin has ectodermal, neuro-ectodermal and mesodermal derivation. Ectoderm forms the epidermis and the epithelial parts like hair follicles, glands and nails. The mesodermal portion of the skin consists of the dermis or corium with its cells, fibres and ground substances. Another important region in the complex organisation of the skin is that of the neuro-ectodermal cells, which differentiate into melanocytes.

Figure 17

Diagrammatic representation of a section of the skin on the sole of the human foot.

(approx. x 100)



(i) The epidermis

The epidermis varies from 0.07 to 0.12 mm in thickness over most of the body but it may reach a thickness of 0.8 mm on the palms of the hands and 1.4 mm on the soles of the feet. The epidermis is stratified squamous epithelium, composed of cells of two distinct lineages. The bulk of the epithelium comprises cells which undergo keratinization and form the dead superficial layers of the skin. The other cellular component consists of the melanocytes, found in the deeper layers of the epidermis, which produce the pigment, melanin. Collectively, these cells comprise the pigmentary system of the skin. The superficial keratinized cells of the skin are continually exfoliated from the surface and are replaced by cells that arise from mitotic activity in the basal layer of the epidermis.

In sections perpendicular to the surface, four layers can be distinguished in the epidermis. The deepest of these is the *stratum Malpighii*, which may be sub-divided into the *stratum germinativum (stratum basale)*, the layer of cells in contact with the dermis, and a layer of variable thickness above it called the *stratum spinosum* (prickle cell layer). The next layer is the *stratum granulosum* or granular layer; then follows the *stratum lucidum* or clear layer and *stratum corneum* or horny layer. The superficial keratinized portion of the epidermis consists of the *stratum corneum* and *stratum lucidum*. Mitotic figures are common in the *stratum germinativum* but are by no means confined to it. As the cells move up into the stratum spinosum, they assume a flattened polyhedral form from their previously cuboidal shape. The *stratum granulosum* consists of three to five layers of flattened cells containing conspicuous granules.

The epidermis is entirely devoid of blood vessels and it is presumed to be nourished from capillaries in the underlying connective tissue by diffusion through tissue fluid, which occupies an extensive system of intercellular space of the Malphigian layer.

(ii) Melanocytes.

Melanin is located in granules, called melanosomes, which are located in the Malpighian layer of the epidermis or in the underlying connective tissue of the dermis. These granules, although found in the Malpighian cells, are however formed by epidermal melanocytes. These cells possess an enzyme system which includes tyrosinase by which the dietary amino acid, tyrosine, is converted to DOPA (dihydroxy-phenylalanine) and thence to the protein-complex pigment, melanin. The melanosomes are somewhat larger in the skin of Australoids, Negroids and Mongoloids than they are in Caucasoids.

(iii) The dermis (corium)

The average thickness of the dermis is approximately 1 to 2 mm. It is thinner on the eyelids and the prepuce (0.6 mm or less) but can reach a thickness of 3 mm or more on the palms and soles. The sculptured surface of the dermis is called the papillary layer and the deeper main portion of the dermis is called the reticular layer. The reticular layer consists of rather dense connective tissue. The papillary layer and its papillae consist of looser connective tissue with much thinner collagenous bundles.

In many places in the skin of the face, cross-striated muscle fibres terminate in the dermis. These are the muscles of facial expression. They are also responsible for the voluntary movement of the ears and scalp. The elastic fibres of the dermis form abundant, thick networks between collagenous bundles. In the papillary layer, they are much thinner and form a continuous fine network beneath the epithelium.

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