The Validity of Bite Mark Evidence for Legal Purposes

Yuan Chang Xu

Student No: 2543308

A mini thesis submitted in partial fulfilment of the requirement for the degree of the MSc in Forensic Dentistry, University of the Western Cape.

Supervisor:

Professor V.M. Phillips

PhD, DSC

Abstract

Bite mark evidence has been admitted into US courts since the 1870s. It quickly gained popularity after the conviction of W.E. Marx in 1974 for manslaughter using primarily bite mark evidence. However, since the development of DNA typing and testing in forensic science, the emergence of wrongful convictions has placed the validity of bite mark evidence admissibility into severe dispute. This mini-thesis is a condensation of the past ten years' worth of literature on the latest researches regarding bite mark evidence. The theory of the uniqueness of the human dentition is analysed. The accurate reproducibility of bite mark on skin with regard to distortion is discussed. Some bite mark court cases, including wrongful convictions are explored. Inconsistent expert opinions and the lack of standards amongst practitioners are also examined. The aim of this study is to summarize the validity of bite mark evidence in the courts of law.

Key terms

Bite mark evidence analysis; uniqueness; validity; expert witness; forensic science; admissibility; legality

DEDICATION

To my grandfather, who always wanted to be learned, but never had the opportunity to suffer it.

CHAPTER ONE

Subtitles:

1: Definition

2: Introduction

3: Forensic odontologists and bite mark evidence

Definition

Bite marks are defined as 'physical alteration in a medium caused by the contact of teeth'[1]. Human bite marks occur primarily in violent crimes like sex-related offences, homicide and child abuse cases[2]. These bite marks have provided crucial physical and biological evidence in the prosecution of such crimes in the courts of law[3]. Forensic dentistry or forensic odontology is the field where dentistry and the law intersect[4].

Introduction

The first documented case in modern history of a conviction based on bite mark evidence occurred in 1692 during the Salem Witch Trials in the United States. Reverend George Burroughs was accused of recruiting girls for witchcraft. The physical evidence against Burroughs were bite marks found on the girls' bodies. In court, the defendant's mouth was forced open and the prosecution compared Burroughs' teeth directly to the bite marks left on the injured girls who were also present. This is the first time in US history where bite marks were used as evidence for conviction in court[5].

In 1870, Ansil. L. Robinson was charged with the murder of his mistress in Ohio, USA. The evidence against him included bite marks on the victim's arm. Although he was eventually acquitted, this trial represented one of the first attempt to admit bite-mark evidence in the court of law in the USA[6].

Sorup A. was the first to publish a contemporary analysis of bite marks in 1924. Transparent paper upon which was inked the incisal and occlusal surfaces of the plaster models of teeth were compared with life size photographs of a bite mark[7].

In 1968, Gordon Hay was the first individual to be convicted using forensic dentistry in the United Kingdom. Based on an oval shaped bite mark bruise on the victim's right breast, which matched Hay's teeth in his dental impression, he was convicted of murder. Although, forensic dentistry was not completely new to the courts at the time, it was contentious. This case set the precedent in the UK for the admission of forensic dental evidence in further cases of rape, assault and murder[8].

In the United States in 1974, Walter Edgar Marx was convicted of voluntary manslaughter partly due to bite marks found on the nose of the victim. The marks were found after an exhumation of the victim's body more than six weeks after the autopsy, embalmment and burial. Three dentists that testified for the state said that they could match an impression made of the bite marks to Marx's teeth. The conviction was upheld in 1975 by the California appeals court whose ruling set a precedent and 'global warrant' for the admissibility of bite mark evidence in USA courts[6].

In South Africa, there are no specific rules of evidence that control the admissibility of scientific evidence. Section 225(1) of the Criminal Procedure Act states that whenever it is relevant in criminal proceedings to ascertain whether any fingerprint, palm-print or footprint of an accused at such proceedings, corresponds to any other finger-, palm- or footprint, or whether the accused has or had 'any mark, characteristic or distinguishing feature' or shows or showed any condition or appearance, evidence of such characteristic or distinguishing feature, including the results of any blood test, is admissible[9].

Forensic odontologists and bite mark evidence

Forensic odontologists' scope of practice includes, but is not limited to, the identification of human remains, age determination, dental profiling and bite mark analysis in cases of assault, murder or abuse. (Please see Appendix A, table 1 and table 2 for bite mark comparison classifications and MacDonald's classification of bite marks respectively)[7,71]. Although bite mark examination and analysis, comparison and identification represent only a small portion of most forensic odontologists' caseload, it has been controversial with regard to legal evidence[10].

Forensic odontologists are often asked to examine evidence and thereafter render opinions in a court of law. Human bite marks occur in the most violent crimes, such as homicide, attempted homicide, sexual assault, assault and child or elder abuse[7]. Bites can occur on both the victim and the suspect. In the first instance, teeth can be used as a weapon of attack and in the second instance, teeth can be used as a weapon of defence. Bite marks can also be self-inflicted either in deliberate false claim cases, mental patients or involuntarily as an emotional response to trauma or to alleviate pain[7].

Bite mark injuries can be found on every surface of the body, but most frequent sites are the breasts and arms. Injuries obtained by a suspect's bite are pivotal to the crime investigations as they are a direct link between the suspect and victim. Crime scene investigators need to recognize and preserve bite mark evidence so that it can be retained properly for examination[3].

The majority of evidence presented in South African courts are witness testimonies, direct or circumstantial in nature. This form of evidence is notoriously unreliable due to the fallacy of memory or previous prejudices. Therefore, since the advent of forensic science, the observation of physical evidence presented in court by expert witnesses, so-called for their specialised

knowledge, skill and/or experience, has greatly improved the validity and reliability of conclusions drawn by legal decision-makers[11].

In the US, from 1974 to early 2000s, the bulk of bite mark evidence consisted of bite mark comparison, whereby an expert analysed a photograph or impression taken of the bite mark on a victim's body that consisted of the morphological bite marks of the perpetrator. This image is compared with the acetate overlay of a suspect/s dentition, which had an impression taken, plaster of Paris models poured and pressed into wax to mimic a bite mark. The comparison would render a conclusion that is either inclusive (positive identification), exclusive (negative identification) or inconclusive (not enough information) [7,10].

Since the early 2000s to date, there have been 30 wrongful arrests or conviction linked to bite mark analysis that have been exonerated using DNA analysis by the highly publicized The Innocence Project, affiliated with the Cardozo School of Law. The reliability and conclusiveness of forensic DNA evidence has been a positive breakthrough for forensic science. However, it has also cast doubt on the traditional types of forensic evidence such as bite mark identification[12].

Chapter Two:

Subtitles:

1: Review of literature

2: Review of bite mark cases

3: Aim and objectives

Review of Literature

Uniqueness

One of the earliest and most often quoted study supporting the uniqueness of bite mark evidence was done in 1982[13]. The study used a computer to compare the bite mark patterns in five pairs of twins. They concluded that 'in terms of occlusal arch form and individual tooth positions, even so-called identical twins are in fact not dentally identical.'[13]. However, in a 2015 paper by Franco *et al*, that systematically reviewed published papers that claims to have proved the uniqueness of human dentition with regards to their technical methodologies. Their report concluded that the small sample size as well as the poor imaging facilities and devices available in 1982 were not adequate to prove uniqueness[14].

The unique nature of the human dentition was also reputed two years later in a study conducted by Rawson *et al*, 1984, that claimed 'human dentition was unique beyond any reasonable doubt.' The study examined 397 bite marks, using 12 parameters, of a general population sample to demonstrate mathematically the individuality of the human dentition[15]. This study was reproduced by Bush *et al*, 2011, with opposing results, in which they concluded that inferences regarding the uniqueness of human dentition for the purpose of bite mark analysis are not supported in an open population[16].

A primary concern is often that the bite mark impression includes only a limited number of teeth, specifically the anterior dentition, and secondly that insufficient details of the unique nature of teeth is rendered during the biting process to enable identification[17].

However, Kieser *et al*, 2007, confirmed the uniqueness of the human anterior dentition by conducting a geometric morphometric analysis of 33 maxillary casts and 49 mandibular casts from a total of 50 individuals to come to the conclusion that 'it appears that the incisal surfaces of the anterior dentition are in fact unique.' Criticism of this study include once again the small sample size and lack of inter-examiner calibrations[14].

Despite the research, a web-based survey in 2003, indicated that odontologists themselves are convinced that human dentition is unique to each living person[18].

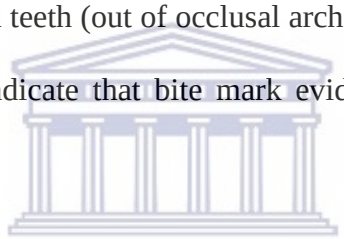
Due to the harsh criticisms aimed at bite mark analysis in the highly critical 2009 United States National Academy of Sciences (NAS) report, many more studies have been published to quantify dental characteristics[19]. That is, what is the probability that another individual would have the same characteristic pattern in their teeth? Or the frequency with which a given set of characteristics occurs in a certain population sample? (Please see Appendix A, table 3 for classification of human bites)[7,71]. The attempt to quantify certain aspects of bite mark analysis allows for statistical scientific backing in an examiners' conclusion. (Please see Appendix A, table 4 for factors influencing human bites)[7,71].

This attempt is notably done by Johnson *et al*, 2009, in a two-year feasibility study undertaken to quantify six dental characteristics. Using 419 volunteers and automated software application Tom's Toolbox, the dentition was digitally scanned, characteristics measured and frequency calculated. Their results demonstrated 'that there were outliers or rare dental characteristics in measurements'. The analysis of the intra-observer and inter-observer consistency demonstrated a high degree of agreement. However, they stated that the sample size needs to be expanded through collaborations with other researchers[20].

However, Sheets *et al*, 2011, compared dental shape match rates in naturally well-aligned and orthodontically treated populations in New York State and found them to be indistinguishable.

Their study also found little variation in dental shape between the male and female participants. Variations studied included the degree of curvature of arch, displacement of incisors and angulation of the canines. Their conclusion was that the dentition is not unique and dental metric detail is not transferred faithfully to the skin[21].

Holtkotter *et al*, 2013, studied the effect of systematic dental shape modifications in bite marks, showing that it was not possible to establish a reliable threshold of how unalike dentitions have to be in order for it to be distinguishable from one another. Changes of plus or minus 1 mm were indistinguishable in recorded bite marks. Only in cases of 5 mm displacement was it possible to distinguish reliably between the different specimens that made the marks. Even more disconcerting, bite marks produced by height-altered teeth mimicked the effects seen in bite marks produced by displaced teeth (out of occlusal arch). All in all, the authors cautioned that the results of their study indicate that bite mark evidence should be interpreted with caution[22].



Martin-de-las-Heras *et al*, 2014, used a specifically developed software to identify one dentition amongst a pool of bite impression to reveal statistically significant bias for the parameters of dental shape, size and angulation[23]. However, there were insufficient parameters to enable proof of uniqueness for Franco et al, 2015[14].

Perhaps proving uniqueness is fundamentally a flaw in itself. In 'the individualization fallacy' as described by Saks and Koehler, 2008, it was suggested that uniqueness cannot be demonstrated[24]. Cole, 2009, went further dismissing uniqueness as a viable descriptor[25].

The 'quantification' of uniqueness is considered irrelevant to both the forensic science and legal system according to Page et al. From their 2011 review article, proving uniqueness is impossible by modern scientific methods from both the mathematical and philosophical viewpoint[26]. They also believe that uniqueness is not an essential requirement for forming

forensic conclusions. The case in point is the Snowflake Syndrome, in which snowflakes are believed to be individually unique due to the large number of possible ways to arrange the approximately 10^{14} molecules in an average snowflake[26]. But even if it should be mathematically impossible does not mean that it is physically not possible. In fact, two snowflakes were found to be visually identical in 1988[26,27].

In a comparative analysis study of bite marks on human skin vs clay by Gorea et al, 2014, in only 44.01% of the 201 cases could the volunteer be identified via a bite mark. Reasoning for low percentile was attributed to the use of volunteers' own skin and therefore pain played a major role[3]. Moreover, 93.34% of the 188 bite marks in clay was identified, demonstrating the impressionability of clay[3]. However, the probability of bite marks occurring in clay is not likely in day to day criminal cases. Therefore, these studies show that the comparative success rate vary primarily according to the substrate on which the bite marks are imprinted. Secondary variation depended on the differences between the multiple methods of comparison which includes hand-drawn, photocopied, scanned and direct cast comparison.

Replicability and accuracy

This brings us to the issue of the replicability of bite marks, since the most common substrate in which bite marks are found is skin. But due to the anisotropic properties of skin, bite mark distortion could impact the accuracy and reliability of bite mark interpretation[19]. Critique from the NAS report stated specifically[19].

- 'The ability to analyse and interpret the scope or extent of distortion of bite mark patterns on human skin has not been demonstrated.

- The effect of distortion on different comparison techniques are not fully understood and therefore has not been quantified'

According to Sorin et al, 2008, bite mark distortions occur mainly from primary dynamic distortions then secondary distortions[28]. Primary dynamic distortions can also be categorised in three main types:

1) associated-events distortions: after initial bite mark an additional lesion appears
2) number variations: the number of lesions is different from 1 (multiple and/or incomplete bites)
3) and other: mixed, incomplete or specific characteristics

Secondary distortions occur after biting and is not directly related to biting dynamic nor with tissue modifications[28]. Three main types:

1) time related
2) distortion, postural distortion
3) recording distortion

These variations can modify both individual and class characteristics significantly, making it difficult to identify the perpetrator accurately or even to say if a certain lesion is a bite mark[28].

Earlier studies by Whitaker DK, 1975, found that distortion occurred on a stationary medium of non-vital pig skin. Accuracy of bite mark was contested since the matching of bite mark on animal skin corresponded in 76% of cases[29].

According to Rothwell and Thien, 2001, the longer the time interval, the greater the distortion, and even preservation of the skin does not necessarily lessen distortion[30].

More recent studies, using human cadaver skin as the biting medium, distortions up to 60% were found by Bush et al[31], 2009 and 80% by Sheets[32], 2012. The authors also found that no two bites were measurably identical. Their error rate of false identifications was as high as 91%[31,32].

A subsequent study of using cadavers by Miller, et al 2009, found that up to 86% of the study models used could not be excluded and that, furthermore, some of the non-biter dentitions 'fit' better than the actual biters' dentition[33].

A 2010 study by Bush et al, of experimentally created bite marks produced by known biters concluded that skin deformation distorts bite marks so considerably that current procedures for comparing bite marks will not be able to reliably exclude or include a suspect as a potential biter 'the data derived showed no correlation and was not reproducible, that is, the same dentition could not create a measurable impression that was consistent in all of the parameters in any of the test circumstances'[34].

Lewis and Marroquin, 2015, measured the effects of skin elasticity on bite mark distortion using inked denture-stamps on forty volunteers' shoulders in four different arm positions. Individual tooth widths and inter-canine distances in each position were also measured and compared. Distortions was calculated at 53.8% and 41.9% respectively[35]. Distortion increased with age, weight and was non-uniform across a dental arch. Acts like suction and tongue thrusting which contribute to bite mark formation are immeasurable and not replicable[35].

Mohamed and Phillips, 2017, attempted to match ideal and accurate replications of bite patterns in wax, using post treatment orthodontic models and using acetate overlay technique. Even then, several patterns were so alike that absolute match was not possible in several cases[36].

Inconsistent opinions

The error rate for participating odontologists in a study of criminal cases by the American Board of Forensic Odontology (ABFO) was indicated to be 12.5% out of a possible 27%. This result shows that the experts were almost half as wrong as they could be and mostly from false positives[37].

In a 2013 study by Page et al, in Australia, 15 odontologists were shown six bite mark images from contemporary cases. They were asked to describe whether the injuries were a) in fact bite marks; b) the possible origin, circumstance and characteristics of the injuries. The study found wide variability among the practitioners in their conclusions for all six images[38]. Unpredictably, those with the most experience (21 or more years) tended to have the widest range of opinions[38]. Examiners demonstrated little consistency in their approach in analysing one bite mark to the next. The study concluded that this 'inconsistency indicates a fundamental flaw in the methodology of bite mark analysis and should lead to concerns regarding the reliability of any conclusions reached about matching such a bite mark to a dentition'[38].

A 2016 study by Reesu and Brown, also highlighted the inconsistencies in the opinions of members of the British Association of Forensic Odontology (BAFO). Twenty-three new and experienced forensic odontologists were requested to give opinions on four cases, with the same request repeated after an eight-week interval. Resultant inconsistencies varied from opinions between odontologists as well as inconsistency in opinion for individual members over the interval period[39].

In a study by Freeman and Pretty, 2016, 100 patterned bite mark injuries were shown to ABFO board-certified forensic odontologists for analysis and three basic questions were asked: (1) is

there sufficient evidence to render an opinion as to whether the patterned injury is a human bite mark; (2) is this a human bite mark; and (3) are any distinct features identifiable. Among the 38 examiners that completed the study, there was agreement on the first question in only 4 of the 100 cases[40]. 90% agreement on all three questions occurred in only 8 of the 100 cases[40].

Sex and race dimorphism

Sex and racial dimorphism studies are available, but there are limited number of publications that are somewhat contradictory. According to Vandana et al, 2008, the mandible canine tooth has the highest evidential value in showing the sexual dimorphism in the western Uttar Pradesh population[41]. Othman et al, 2012, suggested strongly that different race group have some basic difference on arch width and shape[42]. Radmer and Johnson, 2008, also found significant differences in inter-canine arch width between different race groups[43], but this was not seen in Hong et al, 2015[44]. Although Hong et al, 2015, did find the mandibular left canine width to have statistically significant differences between genders[44].

Review of bite mark cases

Successful bite mark cases where conviction was achieved

- The 1979 trial of Theodore Robert Bundy was the first to be televised nationally in the United States. His only physical link to the three murders with which he was charged was bite mark imprints on one of the victims, Lisa Levy's left buttocks. Because he had multiple malpositioned teeth and several broken teeth or chips and defective fillings, Dr Souviron, with confirmation from Dr Lowell Levine, was able to show undeniable similarities between the bite marks and Bundy's dental castings[46]. The jury convicted him for three counts of murder and Judge Edward Cowart imposed death sentences for the murder convictions[47]. (Please see Appendix B, figure 1)

  At the time of Bundy's electrocution in 1989, only 18 or so States had allowed bite mark evidence to be admissible in a court of law. After Bundy's electrocution, a precedence was set in US courts of law and all 50 States had admitted bite marks as reliable testimony[47].

- Richezza Williams was a 13-year-old runaway, whose severely decomposed body was found in an unused storage vault in a Pennsylvania Cemetery in August of 1996. A piece of chewing gum with bite marks was found on site (Please see, Appendix B, figure 2 and 3). The main defendant, Corey Maeweather, was known for chewing packs of gum. Dr Dennis Asen, examined the gum against the defendant's bite and found a conclusive match. Maeweather was convicted of manslaughter and sent to prison for life without parole[45].
- In 1998 Ohio, a 17-day-old Legacy Fawcett was found dead in her crib with bite marks on her body. Only three occupants were home at the time. Dr Franklin Wright testified that only the live-in boyfriend of Legacy's mother could have made the bite mark. The

boyfriend was found guilty of involuntary manslaughter and served eight years in prison[46].

However, DNA tests have proved wrong many of the leading bite-mark experts, including the discipline's founding fathers.

Some of the wrongful bite mark convictions:

- Kennedy Brewer was arrested in 1992 and convicted of murdering his girlfriend's three-years-old daughter. Prosecution's case was built mainly on Dr Michal West's analysis of 19 bite marks on the body of victim that 'indeed and without a doubt' matched Brewer's maxillary teeth only. Expert for the defence opined that the 'bite marks' were post-mortem artefacts caused by crayfish activity in the creek where body was discovered. In 2001, DNA testing on semen samples found on the victim's body excluded Brewer as source. 15 years after his wrongful conviction, he was released in 2008[48].
- Ray Krone is also known as the 'snaggle-tooth killer' due to overlapping bite marks found on a murdered cocktail waitress' breast and neck (Please see Appendix B, figure 4 and 5). He was first convicted in 1992, primarily on Dr R. Rawson's bite mark testimony that the victim's bite marks were a 'very good match' to Krone's teeth. He won a re-trial in 1996, but this time Dr R. Rawson testified further that the defendant's teeth were "a scientific match" to a spotty pattern of blood on the victim's bra[46].

  Eventually in 2002, DNA testing of blood and saliva found on victim's body exonerated Krone when it matched another convicted rapist[48].
- Robert Lee Stinson was sentenced to life in prison in 1984 for the murder of 63-year-old Cychosz, who was also beaten and bitten eight times. Dr L.T. Johnson and later Dr

R. Rawson testified that the bite marks on the victim were made by Robert Stinson. This was the first criminal case in Wisconsin to use bite mark evidence[49].

Later DNA analysis excluded him using a source of saliva found on the victim. Four other bite mark experts have since reported: 'there is little or no correlation of R.L. Stinson's dentition to the bite marks.'; 'their statement drastically overstates the level of certainty attainable using bite mark analysis'[49].

- When Judge Thomas A. Thode sentenced Bobby Lee Tankersley to death in May 1994, he cited the bite marks as evidence that the crime was heinous and depraved. The prosecutor's closing argument to the jury centred on the bite mark evidence: 'This defendant, in essence, signed his name to the body of his victim!'. Unfortunately, the defence did not present a dental expert to refute Dr Rawson's testament that the defendant's teeth 'matched' the bite marks. At the re-trial in 2008, the state's dental expert, Dr Norman Sperber, 'could not identify any individual characteristics of teeth whatsoever in the marks on the neck, ear, chin and jaw area.' In addition, he added 'the techniques of Dr Rawson were questionable, his video presentation misleading, and his conclusions highly dubious.'[50]

  Another forensic dentist, Dr Richard Souviron, questioned whether all the marks on Younkin's body were even bite marks. 'She had a human bite mark on her left breast,' Souviron said, but 'Dr Rawson came up with bite marks on the chin and the right breast,' among other places. 'They were bruises. They definitely, in my opinion, were not bite marks.'

  To date, Bobby L. Tankersley was resentenced in 2008 to life in prison[47,51].

- Steven Mark Chaney was sentenced to life in prison for the killings of John Sweek and his wife in 1987. Forensic Odontologist Dr Jim Hales used the phrase: 'One in a million' chance that the marks could have come from anyone else. 28 years later, he

filed an affidavit in which he recanted his testimony saying it was 'scientifically unsound.' Chaney was officially exonerated in January of 2019 with the help of The Innocence Project. The Texas Court of Criminal Appeals cited this extensively from this case and the 2009 NAS report invalidating the use of bite mark analysis and concluding that such evidence would not be admissible today[47].

Aim and objectives

The aim of this study was to review English literature, assessing the opinions of experts in the forensic sciences field within the past ten years, with regards to the reliability and validity of bite mark evidence and the admissibility of this evidence in a court of law.

The rationale for this study is to summarize the lastest scientific evidence for and against bite mark comparison. Discuss the rationale behind the bite mark comparison methods in use and ascertain the validity of bite mark evidence submission for prosecution.

Chapter Three

Subtitles:

1: Discussion

2: Conclusion

Discussion

Since the 1974 prosecution of WE Marx using primarily bite mark evidence, it signalled a global warrant for the use of bite mark across the world in courts of law. US prosecutors were enthused to use bite mark evidence because of how powerful and inflammatory it can present for jurors.

However, the status of forensic science evidence began to change in the early 1990s'[52]. The impact of the emergence of DNA testing in forensic science, with the consequent discovery of wrongful convictions, has placed bite mark evidence under severe examinations[52]. Concerning factors include the highly subjective opinions of bite mark analysis; the lack of scientific backing to the claims made by experts in court as well as the lack of accepted uniform standards for all practitioners from which to consult[19,46]. Legal commentators highlighted the following areas of controversy: a) accuracy of the bite mark itself, b) uniqueness of the human dentition, and c) analytical techniques[53].

Accuracy, uniqueness and replicability

Bite mark examination ultimately relies on morphometric analysis. This is the comparison of a suspect's teeth characteristics with a photographic image of injury. The parameters considered include size, shape, alignment of teeth and the dimensions of the dental arch[54]. This discipline of analysis is centred on the core assumptions of the uniqueness of human dentition and that this asserted uniqueness is registered in the material that is bitten. This theory remains an assumption with no evidence supporting uniqueness of human dentition[14,16,21,22,55]. And despite the importance placed upon this evidence in the court of law from the mid-70s to

early2000s, the NAS report concluded in 2009 that 'no evidence of an existing scientific basis for identifying an individual to the exclusion of all other' could be found[19].

Subsequent research by Bush, et al (2009); Sheets, et al, (2013); Holtkotter, (2013) and Dyke, (2019), all concluded that distortion could sometimes be as high as 80%[31]; uniqueness cannot be proven[56]; bite marks analysis should be approached with caution[22] and orthodontically treated dentition reduced uniqueness of human anterior dentition and increased false positive matches respectively[57]. (Please see Appendix B, figure 6 and 7 for methods of studying bite mark comparison).

Rivera-Mendoza et al, 2017 noted that bite mark analysis in inanimate objects and foodstuffs seems to offer more reliability than in the skin, but there is great vulnerability in all the steps involved in the procedure[58].

De Sainte Croix et al, 2016, realised the quality of image upon which bite marks are analysed can be varied due to camera models and expertise of the photographer. But using accurate 3D time-lapse animations was expensive and required expertise. Knowledge of the error rate in 3D scanning of dental casts is also critical in digitized forensic cases[2,59].

Since the early 90s, DNA has become the 'gold standard' of forensic scientific evidence worldwide[52]. NAS reports that 'among existing forensic methods, only nuclear DNA analysis has been rigorously shown to have the capacity to consistently, and with a high degree of certainty, demonstrate a connection between an evidentiary sample and a specific individual or source.' However, due to 'systemic judicial pro-prosecution bias' in the US, judges continue the routine admission bite mark expert testimony[52].

In British and the Commonwealth law courts, where the judges are the assessor of evidence, many practitioners choose to use the term 'individualisation' over 'uniqueness', in recognition

of the fact that uniqueness is unproven[26]. Once a practitioner declares uniqueness of a bite mark to the 'exclusion of all others', he/she has usurped the judge's role as the assessor of the evidence[26].

In South Africa bite mark comparison or analysis is regarded as a scientific analysis in which a degree of concordance is demonstrated or rejected. The evaluated evidence is then presented to the court and the verdict left to the judge[60].

Expert disagreement

Minor disagreements amongst experts in any given field is considered standard to allow robust discussions and progressive growth of knowledge. However, disagreements between dental experts have shown to range from minor differences (common) to diverging opinions of whether a bite mark exists at all (not uncommon). In the US, these significant levels of disagreements are admitted by the judge and then tasked to the uneducated jury to ponder during deliberations[7].

In the US, the judicial task has always evaluated the credentials of testifying experts as to whether they meet a degree of respectability. The questions of science are presented to the jury who ultimately looks up to and trusts the credibility of the expert. The scientific aspects of accuracy, reliability or validity are assumed[7,61].

In a five-part investigative series by The Chicago Tribune in October of 2004, 154 court documents of criminal cases involving bite-mark evidence, that reached the appeals courts in state and federal jurisdictions in the US were examined. In more than a quarter of those cases, the prosecution and defence offered forensic dentists who gave diametrically opposed opinions[49].

Although bite mark analysis is considered delicate work, well-qualified experts have differing opinions on the interpretation and use of this type of evidence[6].

A 2013 study by Osborne et al, found that bite mark comparisons are also susceptible to bias if context is given prior to analysis[62]. In addition, the study found experts are more inclined to be overconfident in their decisions[62].

Turvey and Cooley, 2014, believe that disagreements stem primarily from the failure of the profession to set a minimum threshold for bite mark identification[7,63]. The varying patterns and resolutions seen in photographic images of skin injury and inanimate objects (i.e. clothing) brought into the criminal courts by prosecutors shows a significant level of expert disagreement[63].

The 2016 President's Council of Advisors on Science and Technology (PCAST) report found that few empirical studies were undertaken to study the ability of examiners to accurately identify the source of a bite mark. However, among the studies undertaken, the false positive rates were so high that the method is deemed clearly scientifically unreliable[64]. The 2016 report also found that bite mark analysis does not and is far from meeting the scientific standards for foundational validity. In fact, current scientific evidence strongly suggests that examiners cannot consistently agree on whether an injury is even a human bite mark and cannot identify the source of bite marks with reasonable accuracy[64].

When reputable practitioners strongly disagree with each other, it damages the reputation of the field and calls to question the validity of its method. The proponents of bite mark evidence have the burden of proving its validity using current data. However, presently the data shows a disturbingly high false-positive error rate[12].

Lacking standards

There is no accepted minimum number of points of identity required for a positive identification. Experts that have testified in US courts have used as low as eight points of comparison to a high of fifty-two points. Examples include: State v. Garrison (1978)-10 points; People v. Milone (1976)-29 points; State v. Sager (1980)-52 points; State v. Temple (1981)-8 points; State v. Jones (1979)-37 points.[53,58].

An attempt in the 1980s by The American Board of Forensic Odontology (ABFO) to achieve certain scaled minima of evidentiary value failed, due to inter examiner discord and unreliable interpretation of bite mark autopsy and human dentition data[65].

There has been no legal precedent in British courts as to how many features contribute to a positive identification beyond all reasonable doubts[39].

Future of bite mark evidence

According to Reesu and Brown, 2016, opinions on bite marks are still admissible in courts using outdated or limited studies to support its validity[39]. This calls into question even the admissibility of bite mark comparison into courts.

New software that semi-automatically recognize dental landmarks in photographs of human bites, thereby allowing it to be geometrically calculated for comparison against the dental cast have been developed in Spain. Although reproducibility is considered 'excellent', and maximises objectivity by automatization of technique, expert involvement is still required[66].

Some practitioners are concerned that by excluding bite marks in court, it would hamper the efforts to convict defendants in some cases. But, from a scientific perspective, the correct solution, would be to not admit expert testimony based on invalid or unreliable methods, but

rather to attempt to develop scientifically valid methods[64]. Discouragingly, PCAST, 2016, advised against devoting significant resources to such efforts, as they consider the prospects of developing bite mark analysis into a scientifically valid method to be low.

In the 2016, The Texas Forensic Science Commission (TFSC), issued a moratorium on the use of bite mark evidence in future criminal prosecutions until the technique can be scientifically validated[67].

However, bite mark evidence does have a place in the courts of law. Human bite marks yield biological evidence through saliva deposits on both inert and biological surfaces for up to 21 days under realistic crime scene conditions [5,68]. Even bacterial DNA amplified from bite marks and teeth can provide information in the identification of suspect[70]. And in cases where it is not known whether a class individuality is specific, a bite mark evidence can exclude or include a suspect and thereby help narrow down a wide suspect pool[69]. But bite mark evidence is not sufficient for conviction alone. DNA typing must be used in combination as a prosecutorial tool[7,52].

Limitations of study

The validity of bite mark evidence is limited to the quality of the evidence compared. This study cannot decipher the quality of evidence that is been examined between journal articles written in favour or disproving bite mark evidence. This differing or lack of standard is one of the point of contention in the discussion above.

Studies over the 10 years mark had to be reviewed and was quoted due to the lack of newer studies that cements the foundation of bite mark comparison theory.

Conclusion

Bite mark analysis is based on the opinions of practitioners and not validated by facts. The unproven facts include the theory of uniqueness of human dentition, the replicability of bite mark impressions on skin, as well as accurate analysis of bite mark evidence by practitioners.

The accurate replication of bite marks on skin cannot be proven due to the unstable physical properties of skin. The stiffness and anisotropic properties of skin are variables contributing to distortion. And there is no method to measure the different stages of distortion that occurs with every bite mark on skin. Therefore, the accuracy of the evidence is compromised.

Practitioners' analytic techniques lack standards governed by a legal body. Furthermore, experts themselves often do not agree with and/or able to reproduce their own conclusions after a certain period of time. Inconsistent opinions between experts in court are common, including core matters like whether a mark is even from a human bite. Bite mark comparison is highly susceptible to bias and experts are often found to be overly confident. Conclusions are rarely definitive with reasonable certainty the highest opinion given. Inconsistencies between experts are one of the main sources of contention invalidating bite mark evidence.

Sex and racial dimorphism studies are sporadic and limited in publications but also contradictory.

Bite mark comparison can still be used to exclude suspects within a closed suspect pool. But it cannot be used as the main prosecutorial evidence. DNA has outstripped the usefulness of bite mark analysis in most cases. However, biological evidence left within bite marks is beneficial for court evidence. The future of bite mark analysis is limited.

References

1. Herschaft EE, Alder ME, Ord DK, Rawson RD, Smith ES. American Society of Forensic Odontology Manual of Forensic Odontology, 4th edn. Albany, NY: ImPress Printing, 2007. Ch 9: pp257
2. de Sainte Croix MM, Gauld D, Forgie AH, Lowe R. Three-dimensional imaging of human cutaneous forearm bite marks in human volunteers over a 4 day period. Journal of Forensic and Legal Medicine 2016; 40: 34-9
3. Gorea RK, Jasuka OP, Abuderman AA, Gorea A. 2014. Bite marks on skin and clay: A comparative analysis. The International Association of Law and Forensic Sciences (IALFS) 2014, 4,124-8. http://dx.doi.org/10.1016/j.ejfs.2014.09.002, accessed 26 July 2019
4. Bernstein M. Forensic Odontology. In William G. Eckert (Ed.), Introduction to Forensic Sciences, 2nd edition. CRC Press. 1997, pp.295-342
5. Dorion RBJ. 2011. Bite mark Evidence: A Color Atlas and Text. 2nd ed. Boca Raton: CRC Press; 1-5; 217-240
6. Saks MJ., Albright T, Bohan TL, Bierer BE, Bowers CM, Bush MA *et al.* Forensic bite mark identification: weak foundations, exaggerated claims. J Law Biosci 2016,3(3) 538-75
7. Pretty I.A. Bite mark Overlays-An Analysis of Effectiveness. The University of British Columbia, 2000; 6-15
8. Laird W. Watershed case. Br Dent J. 2011; 211**:** 6. doi: 10.1038/sj.bdj.2011.532
9. Faurie A. 2000. The admissibility and evaluation of scientific evidence in court, University of South Africa, Pretoria, http://hdl.handle.net/10500/16774

10. Souviron R, Haller L. Bite mark evidence: bite mark analysis is not the same as bite mark comparison or matching or identification. Journal of Law and the Biosciences, 2017:617-622, doi: 10.1093/jlb/lsx026
11. Visser JM. Defence challenges of forensic scientific evidence in criminal proceedings in South Africa. South African Journal of Criminal Justice, 2015. Vol 29, No 1; pp:24-39
12. The Innocence Project, available online at www.innocenceproject.org, last accessed 30 Dec, 2019.
13. Sognnaes RD, Rawson RD, Gratt VM, Nguyen NB. Computer comparison of bite mark patterns in identical twins. J Am Dent Assoc. 1982;105(3):449-51
14. Franco A, Willems G, Souza PHC, Bekkering GE, Thevissen PW. The uniqueness of the human dentition as forensic evidence: a systematic review on the technological methodology. The international journal of Legal Medicine Nobem, 2015, Vol 129, Issue 6, pp: 1277-83
15. Rawson RD, Ommen RK, Kinard G, Johnson J, Yfantis A. 1984. Statistical evidence for the individuality of the human dentition, J. Forensic Sci. 29 (1) 245-253.
16. Bush MA, Bush PJ, Sheets HD. 2011. Statistical evidence for the similarity of the human dentition. J Forensic Sci 56; pp:118-123
17. Pretty IA, Turnbull MD. Lack of dental uniqueness between two bite mark suspects. J Forensic Sci, 2001;46(6); pp:1487-91
18. Pretty IA. A Web-Based Survey of Odontologist's Opinions Concerning Bite mark analysis. J. Forensic Sci. 2003:48;117-??
19. Committee on Identifying the Needs of the Forensic Sciences Community, National Research Council. Strengthening forensic science in the United States: a path forward. Washington, DC: National Academies Press, 2009. Pp:352

20. Johnson LT, Radmer TW, Wirtz TS, Pajewski NM, Cadle DE, Brozek J, Blinka DD. Quantification of the Individual Characteristics of the Human Dentition. Journal of Forensic Identification, 2009; Vol. 59, No. 6:609-625.
21. Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, Bush MA. Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two-dimensional Study. J Forensic Sci, 2011. doi: 10.1111/j.1556-4029.2011.01731.x
22. Holtkotter H, Sheets HD, Bush PJ, Bush MA. Effect of systematic dental shape modification in bite marks. Forensic Science International, 2013; Vol 228, Issues 1-3; 61-69
23. Martin-de-las-Heras S, Tafur D, Bravo M. A quantitative method for comparing human dentition with tooth marks using three-dimensional technology and geometric morphometric analysis. Acta Odontologica Scandinavica. 2014; 72: 331-6
24. Saks MJ, Koehler JJ. The individualization fallacy in forensic science evidence. Vanderbilt L Rev, 2008;199-219
25. Cole SA. Forensics without uniqueness, conclusions without individualization: the new epistemology of forensic identification. Law Probab Risk: 2009;8(3):1-23
26. Page M, Taylor J, Blenkin M. Uniqueness in the forensic identification sciences-fact or fiction? Forensic Science International, 2011 206; pp:12-8
27. Kruszelnicki KS. Snowflakes Identifical, ABC Science, 2006. Available from: https://www.abc.net.au/science/articles/2006/11/13/1784760.htm, accessed 29th Dec 2019.
28. Sorin H, Cristian CG, Dan D and Mugurel R. Bite mark analysis in legal medicine - Literature review. Rom J Leg Med, 2008; 16 (4); pp: 289 – 298

29. Whittaker DK. Some laboratory studies on the accuracy of bite mark comparison. International Dental Journal, 1975; 25: 166-71

30. Rothwell BR. and Thien AV. Analysis of Distortion in Preserved Bite Mark Skin, J Forensic Sci, 2001; 573

31. Bush M, Miller R, Bush P and Dorion R. Biomechanical factors in human dermal bite marks in a cadaver model, J. Forensic Sci. 2009;54:167–176.

32. Sheets DH, Bush PJ and Bush MA. Bite marks, Distortion and covariation of the maxillary and mandibular dentition as impressed in human skin, Forensic Sci. Int. 2012;223:202–207.

33. Miller RG, Bush PJ, Dorion RB and Bush MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model, 54 J Forensic Sci, 2009;909-14

34. Bush MA, Cooper HI and Dorion RB. Inquiry into the scientific basis for bite mark profiling and arbitrary distortion compensation. Journal of Forensic Sciences, 2010;Vol. 55, No. 4:976-83.

35. Lewis C, Marroquin LA. Effects of skin elasticity on bite mark distortion. Forensic Science International, 2015;257:293–296

36. Mohamed N and Phillips VM. Accuracy of acetate overlays in bite mark comparison: How accurate is an ideal bite pattern? SADJ, 2017; Vol 72 no 10; 456-61

37. Bowers CM. 2009-2010 edition. Identification From Bite marks: Scientific Issues, in Modern Scientific Evidence: The Law and Science of Expert Testimony, eds. David L. Faigman, Michael J. Saks, Joseph Sanders, and Edward K. Cheng, 37:13

38. Page M, Taylor J, Blenkin M. Expert interpretation of bite mark injuries-a contemporary qualitative study, J. Forensic Sci, 2013; 58 (May (3); pp: 664-672).

39. Reesu GV. and Brown NL. Inconsistency in opinions of forensic odontologists when considering bite mark evidence. Forensic Science International. 2016; 266; pp:263-70

40. Freeman A and Pretty I “Construct validity of bite mark assessments using the ABFO decision tree,” presentation at the 2016 Annual Meeting of the American Academy of Forensic Sciences. See:online.wsj.com/public/resources/documents/ConstructValidBMdecisiontreePRETTYFREEMAN.pdf.
41. Vandana MR, Sushmita S and Puja B. Mandibular canine index as a sex determinant: A study on the population of western Uttar Pradesh. Journal Oral Maxillofac, 2008. 12:56-59
42. Othman SA, Xinwei ES, Lim SY, Jamaludin M, Mohamed NH, Yusuf ZYM, Shoaib LA, Hussein NNN. Comparison of arch form between ethnic Malays and Malaysian Aborigines in Peninsular Malaysia. The Korean Journal of Orthodontics, 2012. 42(1); pp:47-54
43. Radmer TW and Johnson LT. The correlation of dental arch width and ethnicity. Journal of Forensic Identification, 208. 59(3);268-274
44. Hong WL, Bashuri B, Ghani AAA, Ashar NAMD, Osman K. A Preliminary study of Malay and Chinese Bite Mark in UKM Using Dental Wax. Jurnal Sains Kesihatan Malaysia, 2015. 13(1) 1-5
45. FilmRise (Oct 11, 2019) Forensic Files – season 5, Episode 11: Lasting Impression. Retrieved from https://www.youtube.com/watch?v=Dl1mz7fReX4
46. Myers AL, Sambriski B, Tucker E and Caruso DB. Bites derided as unreliable in court. Las Vegas Review-Journal, June 17, 2013. Accessed 23 December, 2019
47. Kaplan S. Texas inmate’s 1989 conviction overturned after bite mark evidence discredited. The Washington Post, Oct. 13, 2015, accessed 24 December, 2019

48. Pretty IA and Sweet D. 2010. A paradigm shift in the analysis of bite marks. Forensic Science International, Vol 201, Issues 1-3, 38-44, https://doi.org/10.1016/j.forsciint.2010.04.004

49. Possley M and Mills S. 2008. Guilty, said bite expert. Bogus, says DNA. Chicago Tribune, Jul, 10, 2008, accessed 24 Dec, 2019

50. Metcalf RD, Lee G, Gould LA and Stickels J. BITE THIS! The Role of Bite Mark Analysis in Wrongful Convictions. Southwest Journal of Criminal Justice, 2010.Vol. 7(1).*47-64.*

51. Supreme Court of Arizona. Retrieved from: https://murderpedia.org/male.T/images/tankersley_bobby_lee/cr940168.pdf, accessed Dec 2019

52. Shelton DE. 2010. Criminal Adjudication: The Challenges of Forensic Science Evidence in the Early 21st Century. Univeristy of Nevada, Reno. http://ssrn.com/abstract=1610240

53. Giannelli PC. Bite Mark Analysis. School of Law. Crim. L. Bull. 2007;930

54. Kennedy DM, Stanton J-AL, Garcia JA, Mason C, Rand CJ, *et al*. Microbial Analysis of Bite Marks by Sequence Comparison of Streptococcal DNA. PLoS ONE 2012, 7(12): e51757. doi:10.1371/journal.pone.0051757

55. Franco A, Willems G, Souza PHC, Coucke W and Thevissen PW. 2017. Uniqueness of the anterior dentition three-dimensionally assessed for forensic bite mark analysis. Journal of Forensic and Legal Medicine 46; pp:58-65

56. Sheets DH, Bush PJ, Bush MA. Patterns of Variation and Match Rates of the Anterior Biting Dentition: Characteristics of a Database of 3D-Scanned Dentitions. J Forensic Sci 2013; Vol. 58, No 1, doi: 10.1111/j.1556-4029.2012.02293.x

57. Dyke AEC, Cunningham S, Hunt N, Ruff C. A comparative study to investigate the effect of orthodontic treatment on the uniqueness of the human anterior dentition. Forensic Science International 2018;289;368-73

58. Rivera-Mendoza F, Martín-de-las-Heras S and Fonseca GM. Bite Mark Analysis in Foodstuffs and Inanimate Objects and the Underlying Proofs for Validity and Judicial Acceptance. J Forensic Sci 2017, doi: 10.1111/1556-4029.13586

59. Molina A and Martin-de-las-Heras S. Accuracy of 3D Scanners in Tooth Mark Analysis. J Forensic Sci 2015, Vol.60, doi: 10.1111/1556-4029.12598

60. Bernitz H, Owen JH, van Heerden WF, Solheim T. An integrated technique for the analysis of skin bite marks. J Forensic Sci, January 2008, Vol. 53, No.1, pp194-8

61. Bowers CM. 2006. Problem-Based Analysis of Bite mark Misidentifications: The Role of DNA, 159 Forensic Sci. Int'l. pp.104-9

62. Osborne NKP, Woods S, Kieser J and Zajac R. Does contextual information bias bite mark comparisons. Sci. Justice 2013, http://dx.doi.org/10.1016/j.scijus.2013.12.005

63. Turvey BE, Cooley CM. Miscarriages of Justice: Actual Innocence, Forensic Evidence, and the Law. Academic Press; 1ST Ed, 2014; 6. ISBN: 9780124115583

64. Report To The President, Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature Comparison Methods Executive Office of the President. President's Council of Advisors on Science and Technology. 2016. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_forensic_science_report_final.pdf, accessed 12, 2019, pp83-87

65. Guidelines for bite mark analysis, American Board of Forensic Odontology, J. Am. Dent. Assoc. 112 (1986) pp383–386.

66. Ramos B, Torres JC, Molina A and Martin-de-las-Heras S. A new method to geometrically represent bite marks in human skin for comparison with the suspected

dentition. Australian Journal of Forensic Sciences *2017*.https://doi.org/10.1080/00450618.2017.1356869

67. Texas Forensic Science Commission, Justice through science. Fifth annual report. December 2015-November 2016, https://www.txcourts.gov/media/1440352/fsc-annual-report-fy2016.pdf, accessed 30 Dec, 2019
68. Pfeifer CM, Gass A, Klein-Unseld R and Wiegand P. DNA persistence of bite marks on food and its relevance for STR typing. Int J Legal Med 2017. DOI: 10.1007/s00414-017-1627-1
69. Bowers CM. Forensic Dental Evidence: An investigators handbook, Academic Press 2004, Ch 7, pp137-8
70. Darnell M, Stanton J-AL, Garcia JA, Mason C, Rand CJ, Kieser JA, Tompkins GR. Microbial Analysis of bite marks by sequence comparison of streptococcal DNA, PLOS ONE 2012, https://doi.org/10.1371/journal.pone.0051757
71. Singal K. Role of Bite marks in Forensic Investigations: An Overview. Paripex-Indian Journal of Research 2015, Vol 4; Issue 10, pp 161-2

Appendix A

Bite mark evidence/examination

Bite marks are classified as impression evidence in Saferstein's classification. Analysis of bite mark evidence includes metric analysis and the comparison of pattern or pattern association. Pattern association can be further divided into three classes namely: gross, class and individual[7,71]

Table 1: Bite mark comparison classifications:

Characteristic	Details	Example
Gross	Identifies the general origin of the pattern	A human bite mark usually appears as a semi-circular injury with a central area of ecchymosis, can be surrounded by small areas of incision or bruising
Class	Measurable features of a bite mark that indicate a restricted source or origin.	The individual number and shape of teeth within a familiar arched arrangement in the upper or lower jaws. Measurements of this arrangement can determine whether bite mark created by child or adult
Individual	Individual characteristics are defined as properties of evidence that can be linked to a common source with an extremely high level of certainty.	In teeth, individual characteristics can be: 1) Developmental: • Additional cusps • Macro- or micro-dontia • Genetic abnormalities of tooth forms • Etc.. 2) Acquired: • Restorations • Fractures • Occlusal wear • Etc..

Table 2: MacDonald's classification of bite marks:

Tooth pressure marks	Due to incisal edges of anterior teeth. Stable and subjected to minimal distortion.
Tongue pressure marks	Due to the pressure of the tongue, palatal surfaces of teeth, cingulae and/or palatal rugae impression marks can be produced. This causes distortion of marks.
Tooth surface marks	Scrape marks produced by irregularities in teeth itself due to fractures, restorations etc…
Complex marks	Combination of above

Table 3: Robertson and Hedge classification of human bites:

Stage 1	Scab formation	0-18 hours
Stage 2	Epithelial regeneration	30-70 hours
Stage 3	Sub epidermal granulation	5-12 days
Stage 4	Regression	After 12 days

Table 4: Factors Influencing Bite Marks:

Type of Tissue:	Loose, excessively fat tissue leads to poor definition; highly fibrous or muscular tissue have better definition
Age:	Infants and old age bruise more
Sex:	Female bruise more than males. Female bite marks retain longer period.
Medical status:	Bleeding disorders or skin diseases bruise more
Time:	Time lapse is critical. Depressions in skin will recover within 10-20 minutes, leaving swelling and discolouration. Thereafter, skin starts contracting and harden.
Vascularity:	Intensity of bruising will be more on higher vascular areas like face than in less vascular areas on hand etc..
Histopathologic changes:	Bite marks will turn from red/blue/purple. To blue or black and then brown and yellow within 10 days period.

Appendix B

Figure 1: Photograph of Ted Bundy's teeth.[47]

Figure 2: Photographic image of gum found at site of Richezza William's discovered remains.[45]

Figure 3: Bite mark examination in the case of Richezza Williams[45]

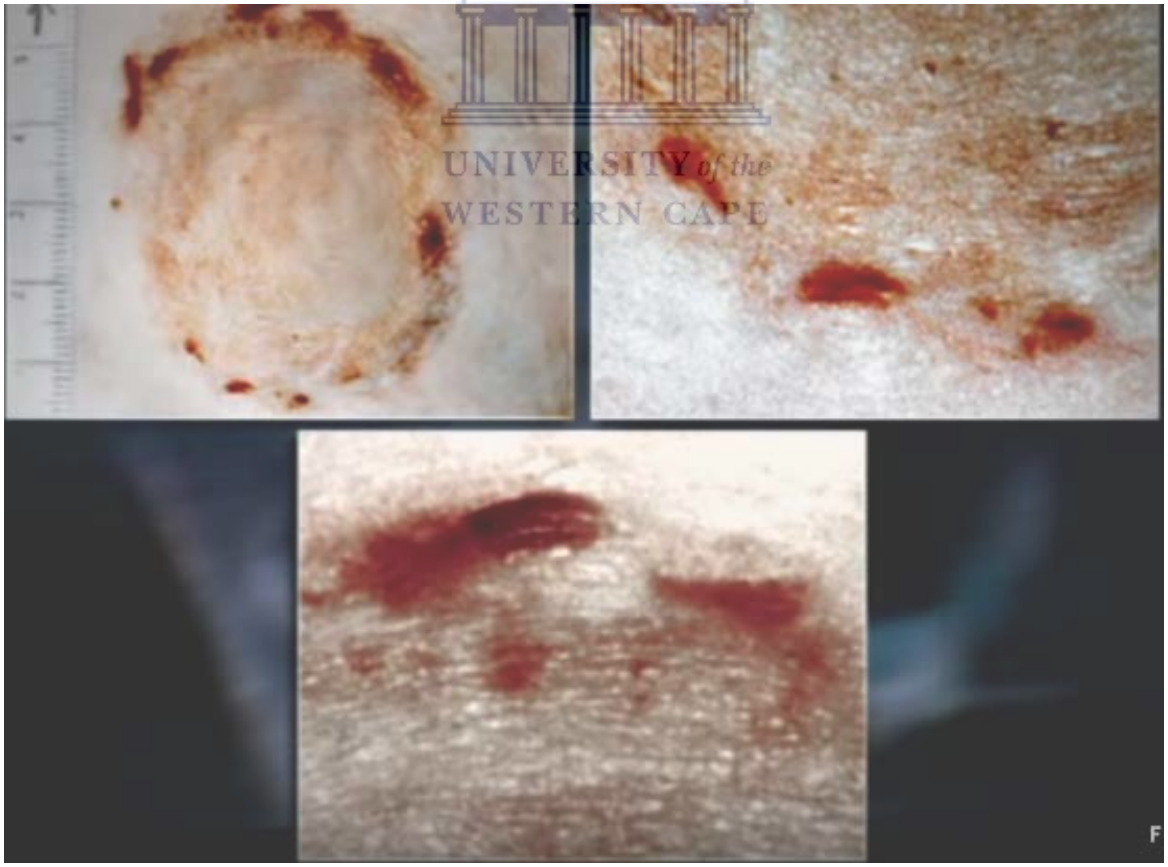


Figure 4: Bite marks found on cocktail waitress' body in the case of Ray Krone[46].

Figure 5: Ray krone's bite mark on polystyrene cup.[46]

Figure 6: An overlay of a bite mark placed on top of a photograph of a bite mark victim to see if the bite could have been made by the person in the bite mark overlay.

Figure 7: Mary and Peter Bush, research scientists at the University of Buffalo, NY, demonstrating a modified Vise-Grip Tool with attached dental mould that is used for test bites in humans or cadavers.