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Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model*

ABSTRACT: In bitemark analysis, the forensic odontologist must consider how the biomechanical properties of the skin contribute to distortion of the bitemark. In addition, one must consider how the bitemark can be distorted by postural movement of the victim after the bite has occurred. A fundamental review of the architecture and biomechanical properties of the dermis is described and evaluated through bites made on cadavers. In order to assess distortion, 23 bites from a single characterized dentition were made on un-embalmed cadaver skin. Bite indentations were photographed. Following various body manipulations they were re-photographed in different positions. Hollow volume overlays of the biting dentition were constructed, and metric analysis of the dentition and all bitemarks was completed. The overall intercanine, mesial to distal, and angle of rotation distortion was calculated. Of the 23 bites made, none were measurably identical, and in some cases, dramatic distortion was noted.

KEYWORDS: forensic science, forensic odontology, bitemarks, bitemark research, human skin, distortion

Bitemarks may be inflicted during violent situations such as sexual attacks, child or domestic partner abuse, and during offensive or defensive combat altercations. In these circumstances the bitemark may be the only evidence linking the biter to victim (1). The ability to properly interpret bitemark evidence can be critical. However, bitemark interpretation remains a complex subject in forensic science. Scientific studies are needed to address fundamental aspects of bitemark analysis, specifically analysis of distortion of a bite in human skin.

The premise of bitemark interpretation is based on two assumptions. The first is that each human dentition is unique. The second is that human skin records this individuality with sufficient fidelity that the biter can be identified, included, or excluded as a suspect. Few scientific studies support or corroborate these assumptions (2). Despite this, bitemark testimony has been admissible in the judicial system (3).

Even with the advent of the Daubert ruling, bitemark testimony has been accepted, although it may be questioned whether sufficient empirical testing, peer review, or error rates have been established (2,3). A number of individuals, convicted on bitemark evidence, have spent years incarcerated only to have the convictions overturned (4,5).

Although there have been studies that address the individuality of the human dentition (6–11), few have tested the transfer to a bitten substrate. Those that make a comparison to a bitten substrate have used media such as wax (12,13) or styrofoam (14–16). Wax and styrofoam behave quite differently from human skin, as they undergo permanent plastic deformation under stress, unlike skin, which exhibits a visco-elastic response to applied stress. A number of recent studies have used nonhuman subjects that closely mimic human skin to evaluate this transfer (17–23).

Only a few studies have examined distortional factors with regard to skin (24–29). The authors of these studies urged further investigation and acknowledged potential for discrepancies. Indeed, one study found a linear expansion of an inked concentric circle on the lateral thoracic wall to be as great as 60% as the arm was flexed and then raised (27).

A bitemark can be distorted because of the biomechanical properties of skin and underlying tissue. The degree of deformation can be influenced by anatomic location, thus affecting tooth relationships within an arch, arch size, and shape. Movement of the victim can also cause postural distortion. Postural distortion occurs when a bitemark is photographed with the victim in a different position than that in which the bite occurred.

Skin behaves in a heterogeneous, nonlinear, visco-elastic, anisotropic manner (30). It also exhibits hysteresis, which affects how long an indentation remains. The issue is compounded by variability between and within individuals and from site to site on the body. These properties also differ with age, weight, and physiologic condition (31,32). Biomechanical properties dictate how a material deforms in response to applied force. When teeth engage skin, a complex interaction takes place. The skin may be pulled and compressed. Although the overall bite may be considered as being a compression injury, locally, where the tooth contacts the skin there is tension. As a bite force is applied, skin strains under tension until either tissue is released or lacerating rupture occurs.

Applied stress (force per unit area) can be measured. The ability of skin to absorb force and deform in a given location is dependent on the underlying tissue structure. The biomechanical property of skin is largely determined by the architecture of the dermis (31). The dermis consists mainly of collagen fiber bundles, elastin fibers, and ground substance which have specific properties that contribute to visco-elasticity, nonlinearity, anisotropy, and hysteresis of skin.

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Visco-Elasticity

At low stress, skin is fairly extensible, but as stress increases, skin becomes more rigid. Therefore, during normal activity under low stress, the skin behaves elastically (31–33). It is this property that causes a light push in the skin by a finger to rebound immediately. However, with increasing stress, skin exhibits elastic and viscous properties, hence the term visco-elastic. For visco-elastic materials, rebounding does not occur immediately. Bite-related tooth indentations will remain in skin before rebounding. Visco-elastic materials must first go through an elastic phase, which occurs at low forces. They then enter the viscous phase as force is increased or maintained. It is the interaction between elastin, collagen, and ground substance that contributes to the visco-elastic properties of skin.

Elastin fibers range from 0.5–0.8 um in width and up to 50 μ in length, are interwoven among the collagen fibers, and compose 4% of fat-free dry weight (30). They possess a rubber-like nature for high extensibility. As skin is pulled by a light force, elastin restores the normal fibrous array, thus quickly restoring skin to its original position (31). As force and extension increases, collagen fibers begin to stretch.

The collagen fiber network comprises 75–77% of the fat-free dry weight of skin. Each fiber varies from 1 um to 40 um and is separate from others along its length (32). They possess high tensile strength and low extensibility rupturing at strains in the order of 5–6% (30,31).

The ground substance is an amorphous gel that fills the spaces between fibers. Its main constituents are mucopolysaccharides. As collagen and elastin fibers are extended under high stress, ground substance is squeezed between the collagen bundles into surrounding tissue. It is movement of the ground substance that results in the viscous behavior of skin (31–35). After stress is released, time permits the ground substance to slowly regain its original position, restoring the original skin topography (31–33). This is the hysteresis effect.

In summary, the properties of the elastin, collagen, and ground substance determine the physical response to applied stress in the skin. These properties dictate how an indentation can be formed and why it subsequently disappears.

Nonlinearity

The mechanical properties of visco-elastic materials alter with the rate of loading or straining, thus load deformation relationship for skin is nonlinear (31,32,34–36). This nonlinearity is described by a "J" shaped stress–strain curve (Fig. 1). The *Y*-axis represents stress, expressed in Pascal units (force per unit area). The *X*-axis is strain expressed as a fraction derived from the change in length divided by the original length. This axis can also be expressed as a percentage elongation. Figure 1 shows the typical curve shape. This is a generic curve and no units are specified, as actual values are dependent on tissue type.

The curve is divided into three phases. Phase I represents the rapid extension of skin under low stress, the elastic phase. The elastin fibers reorient and straighten in the direction of the force. The stress required to do this is low, as it is mainly the elastin fibers that are stretched and the majority of the collagen fibers themselves are not extended.

Phase II represents stiffening of the skin to a point at which further stretch is very limited. As the elastin fibers have already been stretched, the collagen fibers begin to orient in the direction of the stress, straighten, and the skin stiffens (30). Thus skin rigidity is attributed to the fibers progressively becoming aligned and resisting tension along their length. By the end of phase II most of the collagen fibers are straight and oriented in the direction of stress. This makes any further stretch of the skin difficult.

The viscous effects of skin occur in stage II of the stress–strain curve (30,31). Damage to blood capillaries also occurs late in stage II (32). Initially, blanching occurs, as blood flow through the capillaries is restricted. Under increased pressure, capillaries rupture and blood flows into surrounding tissues (in the living) (32). This results in a subcutaneous hemorrhage that, following rebound, may be all that remains to indicate that a bite has occurred.

In the third phase, all of the collagen fibers are fully extended and have straightened. This accounts for the almost linear appearance to the curve in phase III (32). The slope in phase III increases as a logarithm of strain rate. Thus skin appears to resist fracture at very high strain rates (31,32). However, skin exhibits a rate-dependent resistance to stress, and if a load is applied rapidly it may rupture at lower stress levels (34). Rupture, and hence laceration, occur in phase III.

Stiffness of the underlying substrate affects the shape of the stress/strain curve. When substrates of differing stiffness are encountered such as muscle, cartilage, and bone, the curve progressively shifts to the left (Fig. 2). For example, in thin skin overlying the forehead, the skin undergoes very limited elongation and thus phases II and III occur at lower stress levels.

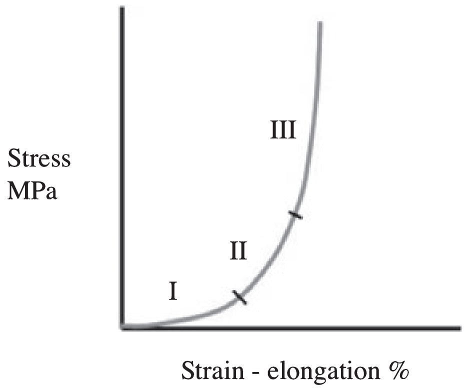

FIG. 1—*Stress/strain curve for skin. The curve may be divided into three phases. In Phase I, most of the elongation takes place under low applied stress. In Phase II, indentation occurs followed by contusion and crushing of capillaries. At some point in Phase III, laceration results.*

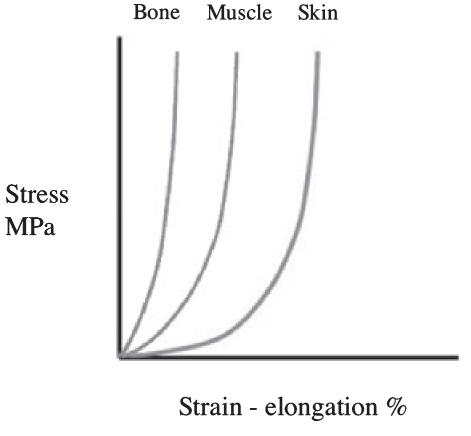

FIG. 2—*The effect of substrate stiffness on the stress/strain curve. As the substrate becomes stiffer, elongation of the skin is limited and the curve becomes more linear.*

Thus, knowledge of the local skin anatomy and consideration of the stress/strain curve are critical to an understanding of how applied stress affects skin during biting.

Anisotropy and Movement

The skin is normally in a constant state of pretension, and this tension is greater in one direction than another. As this tension varies with movement, skin is said to be anisotropic (32,37–39). Anisotropy means that skin possesses different properties in different directions. Thus, properties defined by the stress/strain curve are dependent on preexisting normal tension (31).

Dermal architecture exhibits preferential extensibility that is characterized by the skin tension lines (32). Tension is always greater parallel to tension lines and more relaxed perpendicular to them. Elastin and collagen fibers are under tension along tension lines, so skin extensibility is lower along the direction of these lines. Conversely skin stretches further across tension lines (30–32). This tension pattern, originally described by Karl Langer in 1861, is known as Langer lines (40,41).

Tension lines not only vary between regions of the body, but also with movement (32,41). Borges describes the movement variation as relaxed tension lines (42). Site to site variation of skin extension is dictated by mechanical demands of each part of the body, such as muscle movement and joint articulation (32). Descriptions of skin tension lines have appeared in the literature since the mid-1800s with 36 tension line descriptions, the most widely acknowledged being Langer lines (43).

Thus anatomic location, skin tension, and movement are linked, and play a role in bitemark distortion. Knowledge of skin response to the movement and the areas susceptible to distortion may help the forensic odontologist to better predict and even anticipate bitemark distortion.

The goals of this project were twofold:

1. To determine the degree of distortion (if present) between bites made parallel to skin tension lines compared with those oriented perpendicular to them.
2. To determine the degree of distortion (if any) resulting from movement of the bitemark recipient site subsequent to the making of the bite.

Materials and Methods

Polyvinylsiloxane impressions of the upper and lower dentition were collected from an individual whose casts served as the only biter. The casts were poured into a low viscosity metallographic epoxy resin (Buehler Epo-Thin, Lake Bluff, IL) according to manufacturer's directions. This material has a Shore D hardness value of 78 and is comparable with the teeth that have a Shore D hardness of 70 (the Shore D scale is a measurement of hardness). Thus, epoxy casts are capable of creating indentations and detail reproduction, highly similar to that of natural teeth.

The casts were articulated and mounted to a hand held vice grip. The opening diameter was set at 40 mm corresponding to the biter's dimension. The force produced by the apparatus was tested with a bite force transducer and determined to be within a human bite range of 175–215 N (N = Newton, a unit of force, where force = mass times acceleration). This range was previously established by *in-vivo* volunteer's test bites on the transducer.

Human Subject Review Board (HSRB) exemption was granted for cadaver use. Bites were inflicted on three un-embalmed human cadavers. The use of cadavers to test biomechanical properties of skin is well established. (30–41). Although wound response is not seen in cadavers (edema, inflammation, bruising, and healing), the biomechanical features of the skin are retained for a period of time with properly refrigerated cadavers. Therefore, transfer of indentations and distortion can be studied.

The cadavers were acquired following *rigor mortis,* and were stored at 4°C. The cadavers were allowed to warm to room temperature. Each cadaver received bites on naked skin both perpendicular and parallel to skin tension lines and in various initial biting positions. For example, cadaver No. 1's initial shoulder bite was produced with the arm flexed, medially rotated and supinated, whereas cadaver No. 3 received the initial shoulder bite with the arm straight.

The bite sites included the arm, forearm, lateral thoracic wall, and upper and lower legs. Three photographs were taken immediately after each bitemark. The bitten limb was then moved and rephotographed (Tables 1–3). All photography took place within 10 min of bite marks as many indentations showed signs of rebound.

All bitemark photographs were taken with a Canon Rebel XTi 10.1 Mp digital camera with an ABFO No. 2 reference scale. Using Adobe Photoshop, images were sized 1:1 and metric/angular corrections were done utilizing the Johansen and Bowers method (44).

Bitemark measurements included mesial-distal width of each indentation, intercanine distance for each arch, and relative angle of rotation between teeth. The angle was measured by taking the difference in rotation of the mesial-distal axis between teeth, allowing a comparative measurement. Buccal to lingual incisal measurement was not performed.

A second set of casts was poured under vacuum in Jadestone (Whipmix, Louisville, KY), thus creating models of the biter's dentition for comparison to the photographs of the bitemark. These models were scanned on a flatbed scanner (Hewlett Packard 6100/CT) at 300 dpi resolution. Using Adobe Photoshop, hollow volume overlays were constructed (44–46) and metric/angular measurements were performed using the Johansen and Bowers method (44). Teeth No. 6–11 and No. 22–27 were measured mesio-distally, as was the intercanine distance for each arch and the angle of rotation between each pair of teeth. These measurements were compared with those taken from the bites and the percentage change of each parameter was noted. Similarly, percentage change was calculated through a series of bodily movements. From the measurements made, no two bites were identical, nor did they match the biting dentition.

The experimental intraoperator measurement error of the mesial-distal width and intercanine distance was ± 0.2 mm. The measurement error for the rotation angle was determined to be ± 2 degrees. These calculations were made from measurements of the scanned photographs.

In order to assess the location of the skin tension lines, diagrams from Langer's publications were consulted as well as employing the Borges "pinch" test (40–42). Pinching the skin between the thumb and forefinger highlights tension lines; it is easy to gather the skin perpendicular to tension lines and difficult along them. Repeating the pinch test after limb movement indicated whether the skin tension relaxed.

Results

While the visco-elastic and nonlinear properties influence indentation, anisotropy is the principal determinant of the degree of distortion. Skin tension, direction, and movement played the

TABLE 1—*Anatomic locations of bites, movements, and changes in measurements for cadaver No. 1.*

Location of Bite	Skin Tension Direction	Tension Lines Altered	Movement Difference	Intercanine Difference (%)	M-D* Difference (%)	Angulation (%)
Shoulder	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+6.2	−6.25	0.5 flatter
			Arm flexed	+3.7	−5.5	10 flatter
			Arm straight at side	+4.1	−3	8.6 flatter
Shoulder	Parallel	No	Initial bite—arm straight at side	+10.7	−14.4	26 steeper
			Arm abducted	+14	−4.2	18.5 flatter
			Arm flexed, medially rotated	+5	+2.4	3.2 flatter
Upper arm	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+3.5	−1	18 flatter
			Arm flexed	+10.3	+3.5	12.2 flatter
			Arm straight at side	+1.8	+6.25	12.4 flatter
Lower arm	Parallel	No	Initial bite—arm straight at side	+6.6	+3.75	32 steeper
			Arm flexed, medially rotated	+9.5	+11	7.5 flatter
Lateral thoracic wall	Perpendicular	No	Initial bite—arm straight at side	+4.5	+11	11 flatter
			Arm extended above head	+7.4	+5.2	14.2 flatter
			Arm flexed and medially rotated	+2.9	−8.3	11 flatter
Lateral thoracic wall	Parallel	No	Initial bite—arm straight at side	−12.4	−14	12 steeper
			Arm raised above head	+7.9	+1.8	39 flatter
			Arm abducted	−4.9	−6	13 steeper

*Mesial-distal.

TABLE 2—*Anatomic locations of bites, movements, and changes in measurements for cadaver No. 2.*

Location of Bite	Skin Tension Direction	Tension Lines Altered	Movement Difference	Intercanine Difference (%)	M-D* Difference (%)	Angulation (%)
Shoulder	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+5.4	−2.6	43.7 flatter
			Arm flexed	+4.1	−6.3	28 flatter
			Arm straight at side	+7.8	+17	3.1 flatter
Upper arm	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+8.7	−3	36.7 flatter
			Arm flexed	+6.6	−8.9	25 flatter
			Arm straight at side	+10	+0.3	16 flatter
Upper arm	Parallel	Yes—relaxed	Initial bite—arm flexed	−3.7	+2 max. −2.5 mand.	20.4 steeper
			Arm flexed	−0.5	+0.4 max. −2.8 mand.	16 steeper
			Arm straight at side	+2.1 max. −0.8 mand.	−6.75	7.7 steeper
Lateral thoracic wall	Parallel	No	Initial bite—arm straight at side	+4.5	−2.1	35 flatter
			Arm extended above head	+15	+9.6	38 flatter
			Arm flexed and medially rotated	+7.7	+7.5	42 flatter
Lateral thoracic wall	Perpendicular	No	Initial bite—arm straight at side	−1.5	−9.1	9.5 flatter
			Arm raised above head	−7.3 max. +6.6 mand.	−10.2	12.4 flatter
			Arm flexed medially rotated	+3.7	−14.5	8.5 flatter
Upper leg	Parallel	Yes—tighter	Initial bite—leg flexed, laterally rotated	+5	−3.5	41.7 steeper
			Leg allowed to fall off table	+4.9	−5.9	84 steeper
Upper leg	Perpendicular	Yes—tighter	Initial bite—leg flexed and laterally rotated	−1.7	−5.6	27.9 steeper
			Leg allowed to fall off table	−8.7	−9.7	81 steeper
Lower leg	Perpendicular	Yes—tighter	Initial bite—leg flexed and laterally rotated	+4.6	−5.6	13 flatter
Lower leg	Parallel	Yes—tighter	Initial bite—leg flexed and laterally rotated	+6.8	−6.2	3.1 steeper

*Mesial-distal.

greatest roles in distortion. Figures 3 and 4 depict the approximate location of the bites made and the direction in which Langer lines follow.

Of the 23 bites made in this study, no two bites were visually or measurably identical. Indeed, the variation in appearance of the bitemarks was considerable. Using one individual as the biter allowed for controlled comparison of measurements to a single characterized dentition.

As no two bites were the same, each was considered as a unique event and statistical treatment was not found to be appropriate. However, consistent distortional trends emerged considering bitemark production and subsequent bodily movement. Tables 1–3 show the conditions of each bite and the percentage change of the measured parameters with respect to the original dentition for each cadaver.

Perpendicular to Tension Lines

Bites placed perpendicular to tension lines in firm, relaxed, or stretched muscle showed the least distortion. All showed a widening of the arches, thus flattening the angle of rotation between teeth marks (Fig. 5). Mesio-distal dimensions of each tooth mark were smaller for most of these bites. In situations where skin could be

TABLE 3—*Anatomic locations of bites, movements, and changes in measurements for cadaver No. 3.*

Location of Bite	Skin Tension Direction	Tension Lines Altered	Movement Difference	Intercanine Difference (%)	M-D* Difference (%)	Angulation (%)
Shoulder	Perpendicular	No	Initial bite—arm straight at side	+5.1	−7.3	13 flatter
			Arm flexed and medially rotated	+17.5	−14	8 flatter
Upper arm	Perpendicular	No	Initial bite—arm straight at side	+11.2	−5.7	5 flatter max. 70 flatter mand.
			Arm flexed	+13.6	−5.5 max. +5.2 mand.	20 flatter max. 63 flatter mand.
			Arm flexed and medially rotated	+10	−9.7	13 flatter max. 3 flatter mand.
Upper arm	Parallel	No	Initial bite—arm straight at side	−4	−16.2	66 steeper
			Arm flexed and medially rotated	+5.8	−8.9	88 steeper
Lower arm	Perpendicular	No	Initial bite—arm straight at side	+24	−0.3	81 flatter
			Arm flexed and medially rotated	+17	+3.3	72 flatter
Lateral thoracic wall	Parallel	No	Initial bite—arm above head	+4.1	−13.5	21.6 flatter
			Arm straight at side	−8	−15	13 flatter
			Arm flexed and medially rotated	−19.7	−23.6	11 steeper max. 46 steeper mand.
Lateral thoracic wall	Perpendicular	Yes—tighter	Initial bite—arm above head	+8.7	−12.45	23 flatter
			Arm straight at side	+12.8	−23.5	37 flatter
			Arm flexed and medially rotated	+17.7	−9.8	41 flatter
Upper leg	Perpendicular	No	Initial bite—leg straight	−5.3	−15	37 flatter
			Leg allowed to fall off table	−20	−29.9	76 steeper
			Leg flexed at knee	+9.9	−12.9	43 flatter
Upper leg	Perpendicular	No	Initial bite—leg straight	+13.9	−7.4	52.5 flatter
			Leg allowed to fall off table	−27.9	−29	25 steeper

*Mesial-distal.

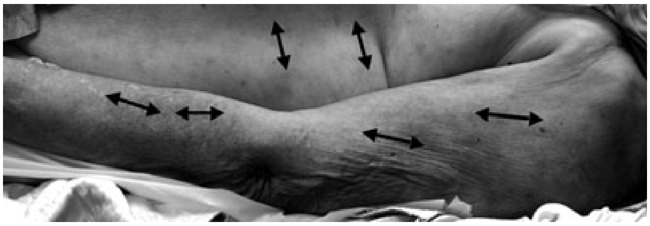

FIG. 3—*Approximate location of the bites made and the direction in which Langer's lines follow on the arm, forearm, and lateral thoracic wall.*

FIG. 4—*Approximate location of the bites made and the direction in which Langer's lines follow on the thigh and calf.*

FIG. 5—*The bite was created perpendicular to the tension lines in firm muscle while the arm was flexed, medially rotated, and supinated. This bite showed the least amount of distortion of all bites in this study.*

gathered because of looseness of the tissue, there was an apparent lengthening of the arches and an extreme flattening of the angle of rotation (Figs. 6 and 7).

Bites that were inflicted in very thin skin showed considerable lingual detail of the upper arch (Fig. 8). Although this was the extreme case for the display of lingual detail, it should be noted that this varied and depended on the degree of firmness of the tissue that was bitten.

Bites in very firm tissue due to initial placement of the body part showed an appearance similar to, though not as extreme as, the bites that were made parallel to tension lines.

Parallel to Tension Lines

Bites that were oriented parallel to tension lines showed greater "dragged" appearance of the upper arch, and marked constriction of both arches which resulted in the angle of rotation between teeth becoming very steep. Figures 9 and 10 show a typical bite made parallel to tension lines. When a bite was attempted in this direction, the upper arch could not maintain hold of the skin and slid until a smaller opening diameter was achieved that could pinch the tissue. Bites placed parallel to the tension lines with the tension relaxed because of flexure of the body part displayed an

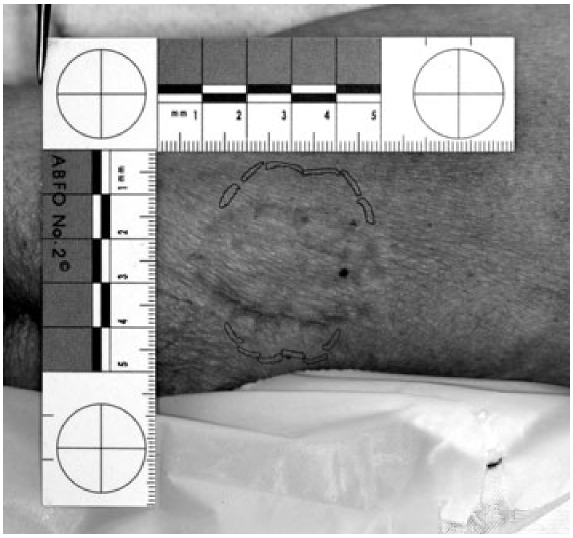

FIG. 6—*A bite created perpendicular to tension lines in loose tissue. The arm was straight and at the side of the body. There is a flattening of the angles of rotation between teeth and apparent widening of the arches.*

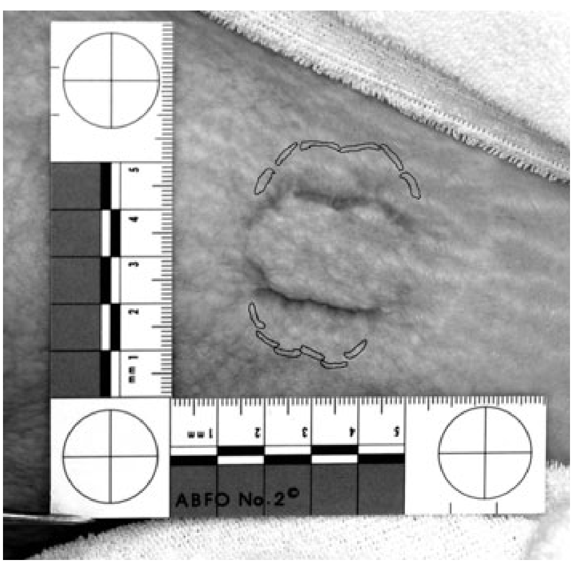

FIG. 7—*A bite created perpendicular to tension lines in loose tissue. This bite was made on the upper portion of the thigh. Note the flattening of the angles of rotation between teeth and a widening of the arches.*

appearance characterized by constriction of the arches, but the "dragged" appearance of the upper arch was absent (Fig. 11). Bites parallel to skin tension lines in areas that had extensive subcutaneous fat had an appearance similar to the bitemarks made perpendicular to the tension lines in loose tissue as there was a flattening of the arch (Figs. 12–14). Bites in fatty tissue made perpendicular to tension lines had a similar appearance as those in muscle perpendicular to tension lines.

Movement

Body movement distorts a bitemark by pulling it in the direction of movement. Figure 15 demonstrates the result of arm extension. The degree of distortion upon movement is dependent upon the range of motion of the body part. Indeed, some bitemarks changed little when the body part was moved, while greater distortion was observed with movement in other areas.

FIG. 8—*The bite on the left was made in very thin skin perpendicular to tension lines. Considerable lingual detail of the upper arch can be seen. The bite on the right was inflicted parallel to tension lines. Note the difference in appearance.*

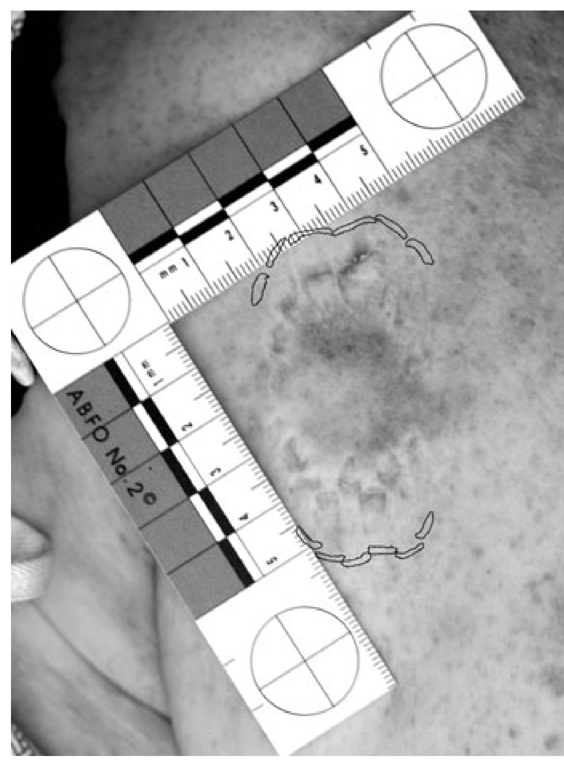

FIG. 9—*A bite made parallel to tension lines. The upper arch shows a "dragged" and constricted appearance while the lower arch shows steepening of the angles of rotation between teeth as well as a constriction of the arch.*

Generally extension led to more distortion (Fig. 16). The lateral thoracic wall for example, was highly extensible when the arm was raised above the head, but this only occurred when the bite was close to the axilla or breast. If the bite occurred caudally, little movement was seen. Thus, in Tables 1–3, lateral thoracic wall bites exhibit variable amounts of distortion.

Body movement usually distorted part of or the entire bitemark. Movement never affected a single tooth alone (Figs. 17 and 18). There are areas of the body that were not as susceptible to postural distortion. Differences are listed in the adjoining tables. Although the original intent was to duplicate the bitten area in each cadaver,

FIG. 10—*A bite made parallel to tension lines. Note the similar appearance to Fig. 9.*

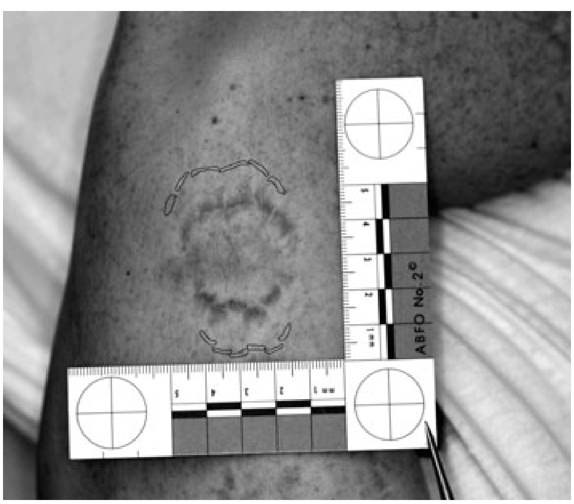

FIG. 11—*A bite made parallel to tension lines while the arm was flexed. Note the constriction of the arches, but the absence of lingual surfaces from upper teeth.*

slight variations occurred as a result of individual body characteristics.

In summary, the range of distortion seen from the single dentition can be described. Values of maximum positive and negative percent change in intercanine measurements were −27% to +24%, giving a range of 51%. For mesial to distal measurements the excursion was −29% to +5%, for a range of 34%. For angulation between teeth the difference was −81% to +80% resulting in a range of 161%. These ranges were the maxima reported in this study. Actual values differed between individuals and bite circumstance. Nonetheless these results suggest that distortion can be a major issue in bitemark production rendering dental comparison complex.

Discussion

A bitemark can be distorted by the biomechanical properties of skin, its underlying tissue, and by subsequent movement of the bite site or the adjacent area. Explanations for these distortions can

FIG. 12—*Two bites created side by side on the lateral thoracic wall. The arm was parallel to the body when the bites were inflicted. Note the differences in appearance.*

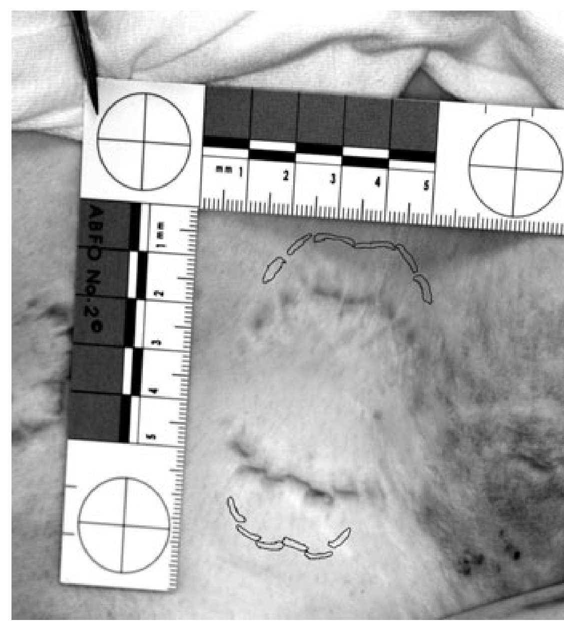

FIG. 13—*Closer view of the bite on the right in Fig. 12. This bite was made parallel to the tension lines in highly fatty tissue, thus mimicking the appearance of bites perpendicular to tension lines in loose tissue as in Fig. 6.*

partially be found in the properties of skin, namely visco-elasticity, hysteresis, nonlinearity, and anisotropy. Consideration of the stress/strain curve for skin provides insight into how the sequence of events that constitutes a bite progresses from elastic deformation through visco-elastic extension.

The use of cadavers excluded the effects of edema, hemorrhage, and inflammation in bitemark production observed in living tissue. This was considered an advantage as it allowed a controlled situation where indentations could be studied as opposed to swollen tissues with bruise patterns. The authors understand that the use of cadaver skin may not replicate living tissue.

The shape of the dentition as transferred to skin in the form of a bitemark is altered at the moment of engagement. The principal

FIG. 14—*Close up of bite on the left depicted in Fig. 12. This bite was made perpendicular to tension lines in fatty tissue.*

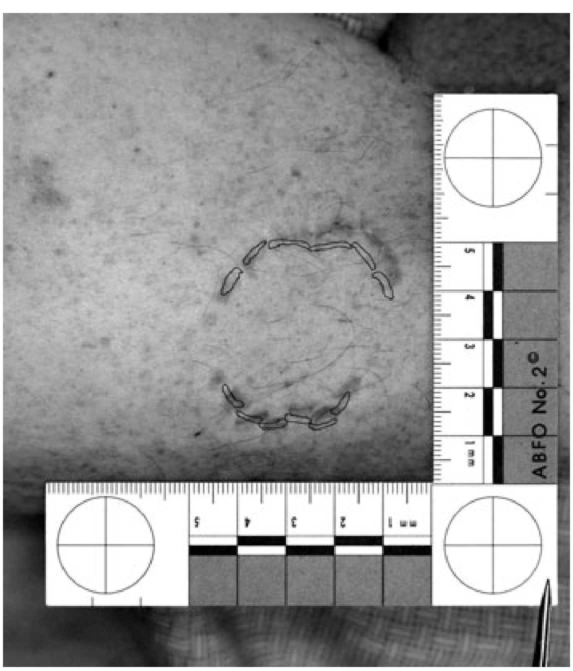

FIG. 15—*Postural distortion of the bite depicted in Fig. 5. The arm is no longer medially rotated and supinated but flexed. Note distention of half of the bite in the direction of movement.*

distortion occurs at this precise moment and the degree of distortion is affected by several factors including teeth gathering skin, stiffness of the substrate, anatomic location, skin tension, and others.

As may be expected, the extensibility of an anatomic location affects the degree of distortion. Distortion due to movement varied depending on anatomic location. In some cases the bitemark appeared completely different depending on the anatomic site relative to tension lines.

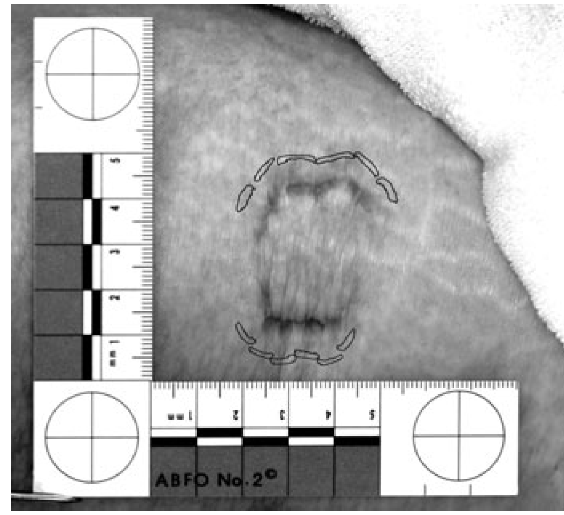

FIG. 16—*Alteration of the appearance of the bite depicted in Fig. 7 with the leg moved from a straight to an abducted position.*

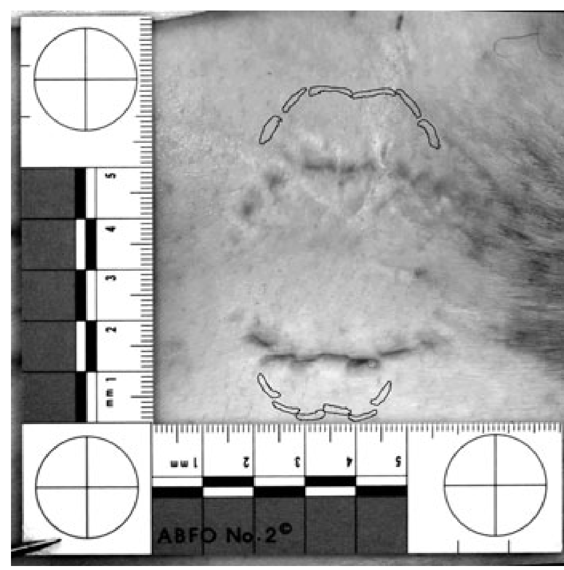

FIG. 17—*Postural distortion resulting from raising the arm above the head. See Fig. 13.*

The bites made on the cadavers exhibited clear indentations. In both living and cadaver skin, indentations do not persist and typically disappear after 30 min. Thus the conditions in this experiment represented the optimum situation pertaining to indentation-type bitemarks. With distortion of up to 80% in clear indentations, interpretation of a bitemark in a live individual in which indentations have faded and only a diffuse bruise remains should be approached with caution.

Because of the dramatic differences seen between bitemarks from the same dentition, each bite had to be considered as a unique event because of the morphologic difference encountered between bites and bitemark location. Definite trends of distortion pattern were observed. This is an important observation from a legal perspective as it can be inferred that each bitemark should be evaluated on an individual basis.

The authors understand the limitations of this study and acknowledge that individual conditions such as pathology, age of the victim, and numerous other factors will alter the

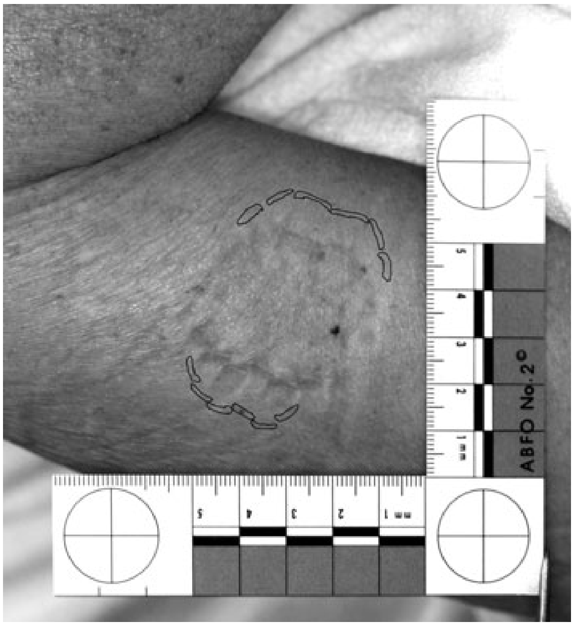

FIG. 18—*Postural distortion resulting from arm movement. The arm was originally straight at the body's side then flexed and medially rotated. See Fig. 6.*

mechanical properties of the skin. In addition, only limited anatomic sites were studied which did not include locations in which the substrate has different properties such as the breast, skull, and ear.

However, the study illustrates that understanding the properties of skin and how it responds to applied stress can be a valuable adjunct to bitemark analysis.

Although the dentition can be accurately measured and described mathematically, its imprint on skin has inherent distortion that a prudent examiner might need to analyze before tendering an opinion. For example, if the uniqueness of a dentition is defined by a five-degree rotation of an anterior tooth in relation to its adjacent dental units and a 20-degree distortion is observed in the bite, then the defining measurement of its uniqueness is insignificant when compared with the effect of distortion. This explainable discrepancy might be difficult to justify without the knowledge of skin biomechanics.

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