TECHNICAL NOTE

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The Bite Mark Standard Reference Scale—ABFO No. 2

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ABSTRACT: A scale of spatial reference for bite mark photography has been developed and evaluated. The scale incorporates both linear and circular graduations to meet the diverse needs of practicing forensic odontologists in the rectification and measurement of photographically recorded bite marks. Its unique L-shaped configuration ensures accurate scaling in both the vertical and horizontal directions and facilitates the gridding of photographs to correct for distortional errors created by oblique camera angles. This paper describes the design and constructional features of the scale and offers guidelines for its effective application to bite mark photography.

KEYWORDS: odontology, bite marks, photography, scale (ratio), bite mark metric, nonmetric, circular reference scale, photographic distortion, image rectification, standard reference scale

Scientific research has provided a sound basis for bite mark identification. Experts' opinions have often been based on nonmetric analyses (associative comparisons) rather than metric analyses (absolute comparisons using physical means) [*1*]. Some analytical techniques of suspect dentitions have become so refined [*2*] that when applied in a comparative way they become quantitative in nature and demand bite mark photographs appropriate for metric analysis.

The introduction of the circular reference scale in bite marks by Stimson [*3*] after Hyzer [*4*] helped experts understand the undesirable effects of photographic distortion on the dental arch form within the bite marks [*5*].

Scale Development

The acceptance and use of a standard photogrammetric reference scale would enable valid metric analyses, insure accurate representations of nonmetric characteristics, and serve as a valuable tool for bite mark research. For these reasons, the American Board of Forensic Odontology (ABFO) asked the authors to develop a standard reference scale for the Board's consideration. The scale shown in Fig. 1 is the result of this work. It was presented to the

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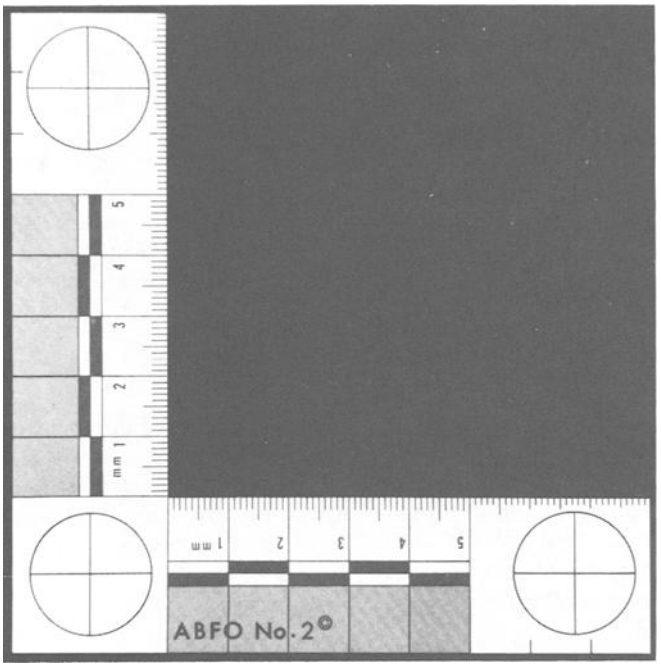


FIG. 1—*ABFO Scale No. 2.*

Board in February of 1987 and has been officially accepted and designated ABFO No. 2.[3] This was the second scale associated with ABFO, so identifying this one as "ABFO No. 2" was considered necessary to eliminate any confusion. The scale is being produced by Lightning Powder Co., Inc. of Salem, Oregon, and is available for purchase from the manufacturer.[4]

The authors' goal was to develop a modestly priced standard reference scale providing the information needed to recover maximum information available from high-quality bite mark photographs. The ideal material to use in the construction of a scale would be steel, but its use proved to be prohibitively expensive. Instead, 40-mil (1.016-mm) polyvinylchloride (PVC) was determined to be a more cost-effective alternative. Laminated in three layers, each 13.5 mil (0.343 mm) thick, it is adequately rigid, dimensionally stable under conditions of reasonable service, and provides a good substrate for the printing of scale graduations. Tests conducted with various color combinations revealed that a white matte background with contrasting black graduations gave the most readable results even in moderately over- and under-exposed photographs. The inclusion of alternate bars of black and white makes it possible to salvage useful metric reference information from poorly exposed photographs in which the finer graduations cannot be resolved.

Odontologists frequently suggested the inclusion of a color patch or gray scale or both in the photograph. It became apparent that the addition of color patches would increase manufacturing difficulties and cost to intolerable levels. Further investigation revealed that as a practical matter photographic color laboratories and forensic science photographers gener-

[3]The reference scale was accepted officially by the American Board of Forensic Odontology, 18 Feb. 1987, San Diego, California.

[4]Lightning Powder Co., Inc., 1230 Hayt, S.E., Salem, OR 97302-2121 (1-800-852-0300).

ally use only a gray scale as a photometric reference in color printing. Consequently, it was decided to include only a gray scale having approximately 20% reflectance.

The metric system was selected as a primary basis of measurement in designing the scale, but in order to also incorporate the English system frequently used in law enforcement, both legs of the scale are 1 in. (2.54 cm) in width. The 80-mm length of the inner edges of both legs is considered adequate for use in all but unusually large bite marks. Three circles, each 20 mm in diameter, are included on the scale. These are considered large enough for precise work under practical conditions of use for purposes of image rectification and measurement. The requirement for three circles in the image for reliable rectification has been pointed out by Hyzer [*6,7*]. Lines drawn through the centers of the three circles form a right triangle with sides equal to 80, 80, and 113.14 mm.

Photographic Techniques

The single most important consideration in using the scale is in positioning it relative to the bite mark or that portion to be depicted. The plane of the scale should be selected so that it is closely coincident with the most common plane of the bite mark. One precise and convenient way to accomplish this is to support the scale mechanically as shown in Fig. 2.[5] It is very difficult to hold the scale between the fingers without obscuring important parts of the scale with fingers (see Fig. 5). The parallax error resulting from out-of-plane displacement between the scale and the bite mark is illustrated in Fig. 3 and may be calculated as follows from Hyzer [*8*]:

$$E = \frac{100d}{S} \tag{1}$$

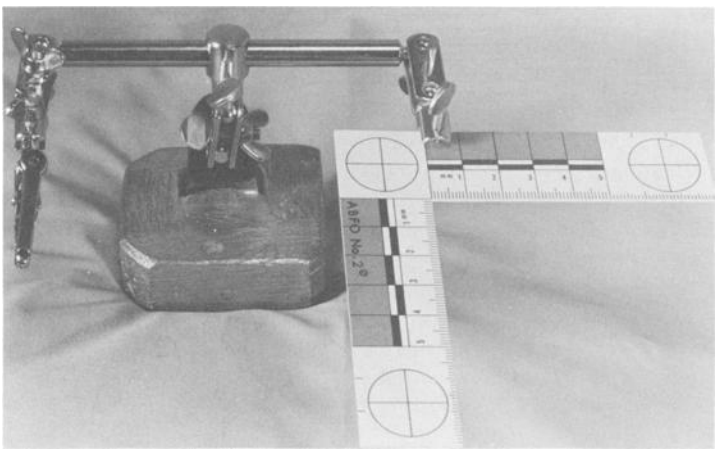


FIG. 2—*"Helping Hands" positioning device. The base has been modified by the addition of cast lead to provide a convenient support for the scale that is far more stable and less intrusive than human fingers.*

[5]Archer, "Helping Hands" obtainable from Radio Shack. Molten lead may be added to its base to add stability.

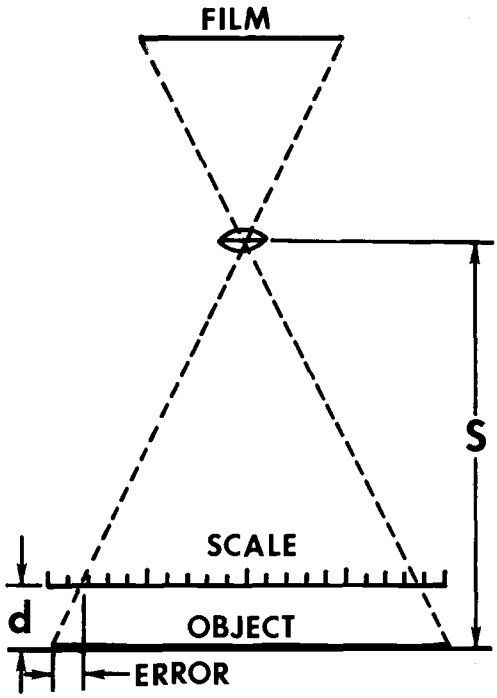


FIG. 3—*Parallax error resulting from out-of-plane displacement between the scale and the object.*

where

E = parallax error in percent of distance measured,
d = distance between the planes of the scale and the object surface, and
S = distance between the object plane and the camera lens.

For a given out-of-plane displacement (d), parallax error (E) is reduced in inverse proportion to camera distance (S). It is for this reason that long-focal-length macro lenses are preferable to lenses of short focal length. The scale should also be closely adjacent to the bite mark, and where possible, positioned midway in its depth dimension.

There are three primary considerations that require attention in positioning the camera relative to the bite mark and the scale: (1) the required portion of the bite mark and the entire widths of the two legs of the scale should be well within the camera's field of view, (2) the film plane should be closely parallel to the plane of the scale, and (3) the camera should be firmly mounted, not only to facilitate meeting the above conditions, but also to avoid any camera movement during exposure and between successive exposures. The use of a tripod is essential.

Precise framing is easily accomplished with single lens reflex (SLR) cameras and large-format cameras equipped with ground glass focusing screens. A camera without a high-quality macro lens that does not have through-the-lens viewing and focusing capabilities is less than adequate for bite mark photography. The bite mark and surrounding scale should be centered in the frame with a small space to spare around the outside edges of the scale and the bite mark as seen through the viewfinder.

Parallelism between the scale and film plane is accomplished by placing a small mirror in the plane of the scale, then moving the camera until the reflected image of the camera's

lens is centered in the focusing screen (Fig. 4). The mirror is removed before making an exposure.

The unique design of the scale permits the construction of grid lines across the photograph at 1-cm intervals (Fig. 5). Distance between these lines can usually be interpolated with sufficient accuracy for most practical applications. Image distortion introduced by minor lack of parallelism may be rectified in the printing process by appropriate tilting of the easel relative to the negative in the enlarger. The three circles inscribed on the scale facilitate this operation. These methods will be discussed in greater detail in the next section of this paper.

Unlike using a simple ruler, consideration must be given to potential shadows caused by low-incident angle cross-lighting methods commonly suggested in bite mark photography. With flash photography, shadow formation can be previewed by projecting a spotlight or strong flashlight beam along the same axis of illumination as the flash.

Analytical Considerations and Techniques

The overall accuracy of scale ABFO No. 2 is ±0.1 mm or ±1% for the major centimetre graduations. Scale divisions were checked against a Gurley comparator consisting of a precision glass scale graduated in 0.1-mm divisions that can be read to a precision better than ±0.05 mm. The end centimetre graduation lines and the ends of the scale are subject to the greatest error and should be avoided in making measurements. The widths of the two legs are 1.000 ± 0.002 in. (0.005 cm), which translates into a percentage error of ±0.2%. The legs are mutually perpendicular to ±2 min of arc. The internal and external diameters of the three circles are 19.75 and 23.0 mm, respectively. The error in placement of the three circles is within 0.25% of the nominal 80-mm separation between their centers.

Photographic images of bite marks are usually analyzed in enlargements made from the original negatives or transparencies. The three circles imprinted on the scale provide one convenient method of checking and correcting for distortion during the enlarging operation. Lack of parallelism between the planes of the scale and film or between the planes of the

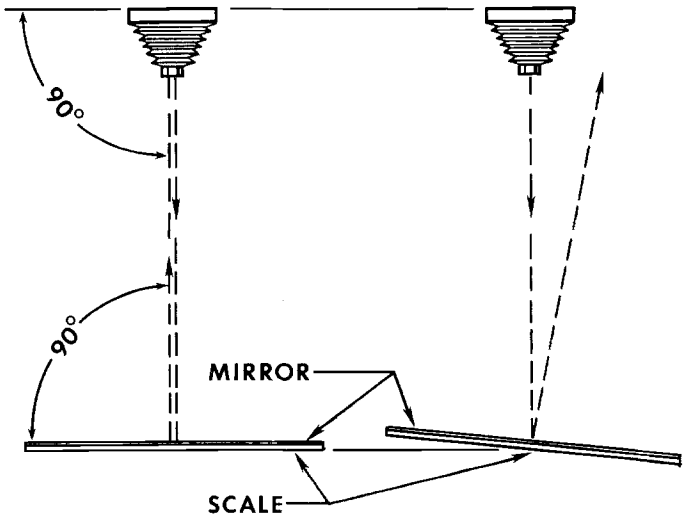


FIG. 4—*A mirror laid on top of the scale aids the photographer in obtaining strict parallelism between the scale and the film plane by centering the reflected image of the camera's lens in the view finder* (left). *Improper mirror and scale alignment is illustrated in the righthand drawing.*

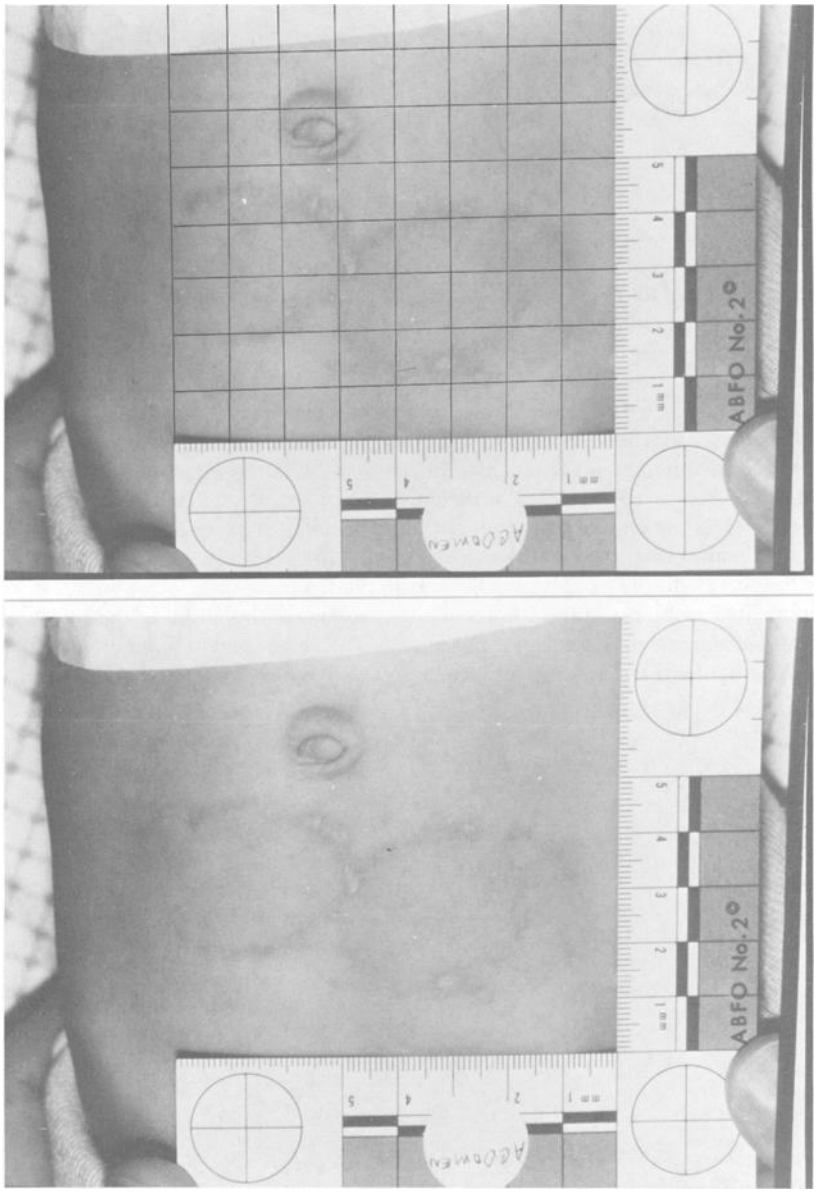


FIG. 5—*The bite mark photograph* (left) *has been gridded in the righthand view.*

negative and enlarging paper will result in distortion of one or more of the three circles. This distortion can be checked by comparing the images of the three circles in the print with circles of the same diameter in a drafting template.[6] The three circles should be identical in diameter and truly round. A circle photographed at an angle θ (Fig. 6) is imaged as an ellipse (Fig. 7), in which the ratio of the minor axis (A) to major axis (B) is given by:

$$\text{Cos}\ \theta = A/B \tag{2}$$

Conversely, the angle θ may be determined as follows from measurements of the minor and major axes:

$$\theta = \text{Cos}^{-1}(A/B) \tag{3}$$

Images with perspective distortion can be rectified by tilting the easel of the enlarger relative to the negative so that the three circles are imaged as true circles having identical diameters. The angle of easel tilt is estimated by taking the average angle θ obtained by means of Eq 3 for all three circles in the scale. This rectification operation is also facilitated by using the drafting template mentioned earlier to check the size and roundness of the projected circles. Perfect rectification requires that the lens-to-film distance be identical in the enlarger and camera. Some technicians prefer to use the same lens for both purposes, which offers the additional advantage of compensating for any lens distortion as well [*9*]. Properly rectified, distances throughout the recorded image that fall in the same plane as the reference scale can be measured directly in scale dimensions.

The circular template also aids in producing enlargements of precise magnification. For example, a $\times 3$ enlargement is made by superimposing the projected images of the 20-mm circles on the scale with the 60-mm circular hole in the template.

Measurements can be made from unrectified enlargements by gridding the image and interpolating distances between the grid lines. This is accomplished by extending the 1-cm graduations on both legs of the scale entirely across the photograph using a sharply pointed

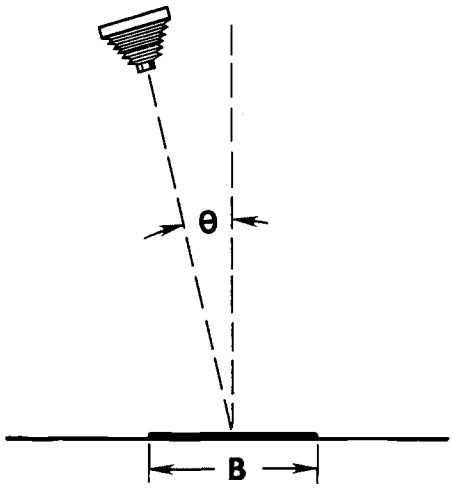
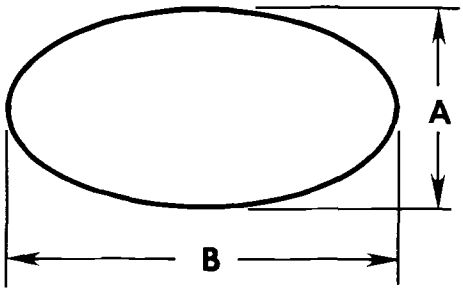


FIG. 6—*A circle of diameter* B *appears elliptical in shape as in Fig. 7 when viewed at an oblique angle* θ.

[6]Picket True Metric Circle Master No. 1304 available at most drafting supply houses.



$$\cos\theta = \frac{A}{B}$$

FIG. 7—*Image of the circle shown in Fig. 6. The diametral distance* B *is reduced to* A *along the viewing axis.*

scribe that cuts through the emulsion layer or a size 00 drafting pen filled with india ink (Fig. 5). Instead of being square, the areas between neighboring grid lines will be trapezoidal in shape if the object and image planes are not strictly parallel. The location of any image point within these areas is measured by factoring its distance between adjoining grid lines in both directions.

Conclusions

The acceptance of the ABFO No. 2 Reference Scale by the American Board of Forensic Odontology adds a new dimension to bite mark photography. An ordinary SLR camera equipped with a high-quality macro lens in combination with this scale becomes an instrument capable of providing accurate spatial measurements. The three circular reference scales allow detection and correction of errors in parallelism between the object and film planes thereby permitting more accurate appraisals of bite mark arch forms. In research, the scale provides valuable assistance in the photographic quantification of bite marks, evidence collecting techniques, and analytical procedures. It could contribute to the development of new techniques such as video-computer analytical comparisons. When a bite mark photograph contains this standard of spatial reference, the examiner can place reasonable confidence in the information it provides, even though the scale itself may not be available for his inspection. The usefulness of the ABFO No. 2 Reference Scale is not limited to bite mark photography alone. Potential applications exist in many other fields of forensic science where metric photographs are required.

Acknowledgments

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