TECHNICAL NOTE

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Photographic Evidence Protocol: The Use of Digital Imaging Methods to Rectify Angular Distortion and Create Life Size Reproductions of Bite Mark Evidence*

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ABSTRACT: Bite mark evidence seen in skin injuries or objects is commonly photographed for evidentiary documentation, preservation, and analysis. Distortion in forensic evidence photographs diminishes the outcome of analytical procedures available to the forensic odontologist. Inaccurate positioning of the evidence, camera, or measurement reference scale creates perspective and parallax distortion of the captured image. These variables must be eliminated, if possible, to ensure reliable results derived from comparison of the suspect teeth and the bite mark. Detection and measurement of camera/evidence/scale misalignment is the threshold step in evidence evaluation, and is possible through digital imaging methods coupled with established methods. Correction (rectification) of perspective distortion is possible through the application of additional digital editing techniques. This study establishes type categories of perspective and parallax distortion seen in bite mark evidence, validates the use of the digital imaging tools of Adobe® Photoshop® to correct certain types of distortion, and establishes a forensic protocol to verify the accuracy of evidence photographs requiring dimensional accuracy.

KEYWORDS: forensic science, forensic odontology, forensic dentistry, computers, Adobe® Photoshop®, digital, off-angle distortion, parallax distortion, perspective distortion, photography, digital imaging, rectification, bite mark, theta, two dimensional scale, life-size magnification

This paper discusses digital rectification processes and resizing methods (1). An accompanying study is presented to validate digital processes that are performed on photographic evidence.

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Photography is a fundamental tool of forensic science (2). Recently, the use of digital imaging methods has been suggested as an improvement upon conventional photographic and other visualization methods (3,4). Visual reproduction of evidence is universally applied as a substitute for physical objects, transfer impressions, and imprint evidence recognized as being relevant to criminal investigations. Bite mark identification evaluates two and three-dimensional physical evidence for comparison with suspect dentitions (5). Photographic control is important as the preponderance of bite mark cases utilize photographs as the sole evidence available for analysis (6). These cases pose comparative shape association and metric analysis of physical characteristics as the analytical tasks directed onto questioned and known evidence (7). Forensic protocols for photographic reproduction of crime scene, autopsy, and other physical evidence demand the placement of a linear measurement scale adjacent to the evidence sample (8) for later use in the fabrication of life size images (9). The literature suggests that metric and shape comparison analysis requires parallelism of the film plane (or CCD sensor) of the camera, a linear scale, and the evidence (10). When these steps are strictly followed, objects and patterns in the image are later reproducible as two-dimensional representations that can be routinely enlarged to 100% (life-size) or higher magnifications. The linear scale permits the examiner to insure the photographic evidence possesses dimensional accuracy and is a true representation of the original object. A two-dimensional scale, such as the ABFO No. 2 (Lightning Powder Co., Inc., Salem, OR.), allows the width and the height of the evidence photograph to be independently established using the digital methods described below. The ABFO No. 2 scale contains three circular reference targets that permit the examiner to determine whether the image capture device (conventional film or digital) meets the criterion of proper alignment of the camera and the object's scale. Evidentiary value is diminished when the photographic evidence, the linear measurement scale, and the camera placement lack proper mutual alignment. Perspective (angular) distortion within the photograph is evidenced by the circles in the scale appearing as ellipses. Parallax distortion occurs when the scale and the object are not on the same plane. The use of a simple trigonometric formula permits the determination of the amount of perspective distortion evidenced by the ellipse. Two axes exist in an ellipse, the major axis, and the minor axis. The COS^{-1} of the ratio of the minor axis (A) and the major axis (B) denotes the camera's

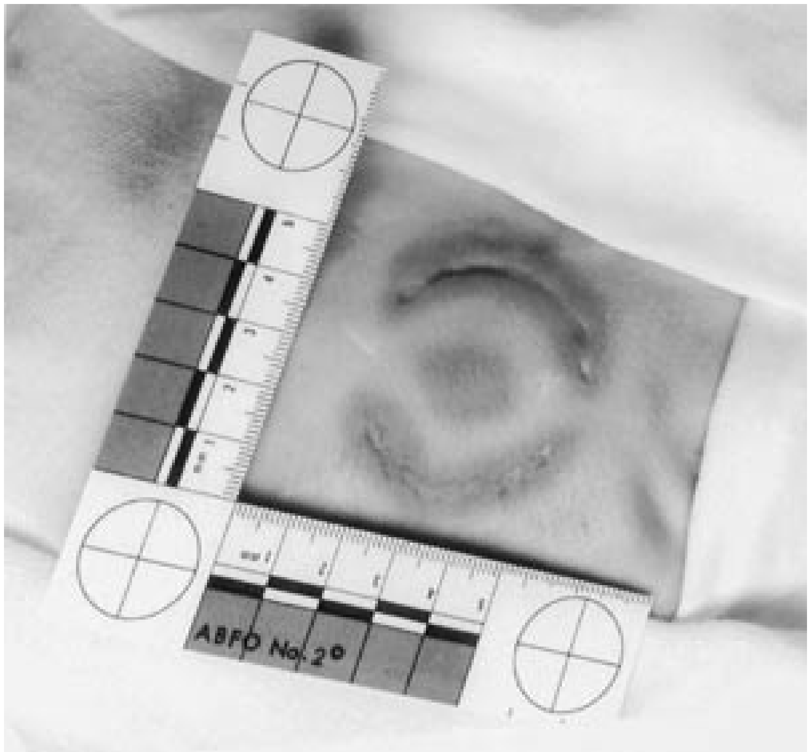

FIG. 1—*Type I distortion: The scale and the object (bite mark) are on the same plane but the camera angle is not perpendicular to this plane.*

degree of arc off the plane perpendicular to the object. Without rectification of this distortion, the photographed evidence sample will not be representative of its true shape and dimension.

The authors have developed a convention for categorizing photographic distortion derived from four common bite mark photographic situations. These distortion types are classified as Types I–IV (only Type I distortion correction will be addressed in this paper).

Categories of Off-Angle Distortion		Solutions
Type I:	Entire scale and evidence on the same plane. The camera is not aligned properly.	Digital or conventional rectification.
Type II:	Entire scale and evidence are not parallel.	No correction possible using scale.
Type III:	Portion of scale is off plane.	Rectify using parallel portion of scale.
Type IV:	Scale is bent, curved, or skewed.	Rectify using parallel portion of scale.

Type I Distortion Detection and Digital Correction

Type I distortion occurs when the scale within the photograph is on the same plane as the evidence sample (bite mark); however, the camera angle is not perpendicular to that plane (Fig. 1). The ABFO No. 2 Scale adjacent to the bitemark shows perspective (off-perpendicular) distortion due to camera misalignment. This off-angle component is called THETA (Fig. 2). The number of degrees the camera is off-angle (non-perpendicular to the evidence) is derived from the equation Theta $= \mathrm{COS}^{-1}$ A/B. A is the length of the ellipse minor axis and B is the length of the major axis (Fig. 3). The

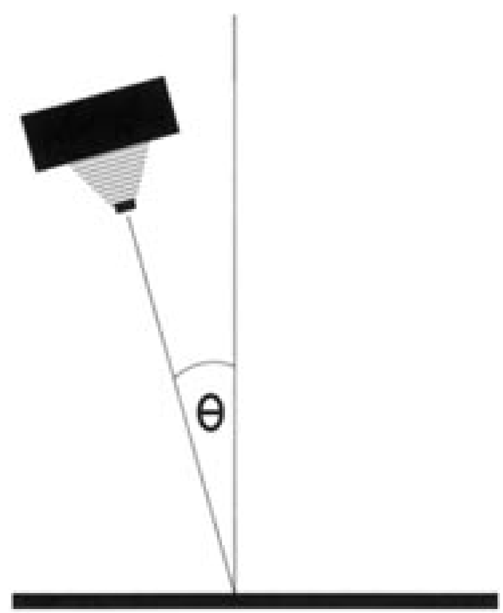

FIG. 2—*Theta is the angle (in degrees) that the camera is off perpendicular from the object plane.*

relationship of A/B to photographic distortion is seen in Fig. 4. Notice that increasing theta values (as evidenced by decreasing A/B value) exponentially increase the photographic distortion.

Each evidence photograph must be evaluated for photographic distortion, and this distortion must be corrected before a meaningful analysis can be carried out. Type I distortion can easily be corrected using the "Distort" (11) function within the Photoshop® program. Once this distortion has been corrected, the image can be accurately resized to life size.

The protocol the authors suggest involves two separate steps: The first step is elimination of perspective distortion (Type I). The second step is resizing to produce a 1:1 reproduction.

These methods use the digital image editor Adobe® Photoshop® 5.5 program, a desktop computer, and a flat bed scanner. Photoshop® is a commercially available digital imaging program that is operated on laptop and desktop computers with sufficient chip speed and RAM (Pentium II or equivalent and at least 96 MB RAM) to open the multi-megabyte image generated by high-resolution digital capture devices.

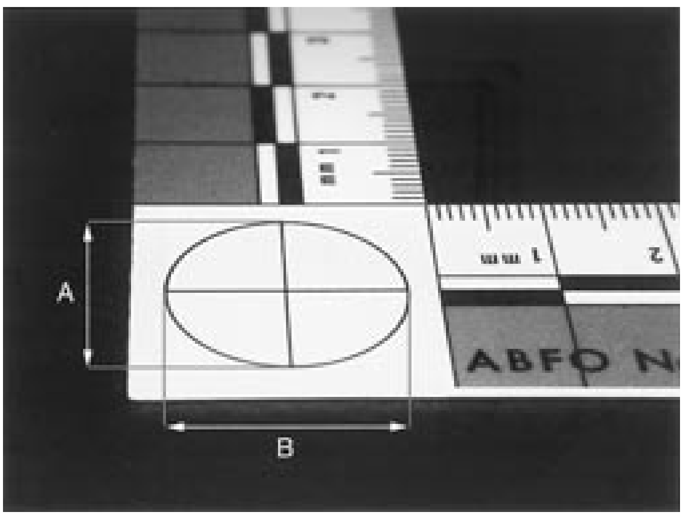

FIG. 3—*The numerical value for Theta can be calculated using the formula: Theta* $= COS^{-1}$ *A/B where A is the minor axis and B is the major axis of the circular reference shape.*

The program accepts raster-based image formats (.JPG, .BMP, and others). It is noted for diverse imaging functions and visual editing tools that allow the computer monitor to be used as a comparison microscope. Questioned and known sample images may be tiled side-by-side or superimposed as layers of differing opacity. The examiner also has the ability to create magnified images (200 to 300%) when the original digital image has been captured at near photo quality resolution (300 dpi). The visual comparison of physical features on the computer monitor permits a large field of view and robust control over image quality. Digital photographic correction features of Adobe® Photoshop® supplant the historic use of conventional photographic manipulation and, in some circumstances, allow better control of metric analysis of relatively small and complex shapes (11).

Materials and Methods

A grid of known dimensions (4 cm^2) was fabricated for the purpose of evaluating the effect of angular distortion on the grid's shape at varying camera angles (see Fig. 5). This grid was also used to evaluate the effectiveness of the digital image rectification and digital resize procedures. Each corner of the grid was designated by a letter (A,B,C,D). The internal angles of the four corners each measured 90°.

The photographic effect of experimentally produced perspective distortion was tested using a digital camera that captured an image above the grid in five positions. These positions are described as angles of incidence (theta) from the recommended perpendicular. These angles were 0, 10, 20, 30, 40, and 50°. The zero position acted as a control to establish the perpendicular characteristics of the grid. An ABFO No. 2 scale was placed in the same plane as the grid for each image. The photographs were taken using a Nikon® Coolpix® 950 digital camera on automatic exposure and "fine" resolution setting. A movable stage was used to incrementally vary the amount of camera off-angle positioning. The camera CCD sensor-to-target distance was not held constant through the testing in order

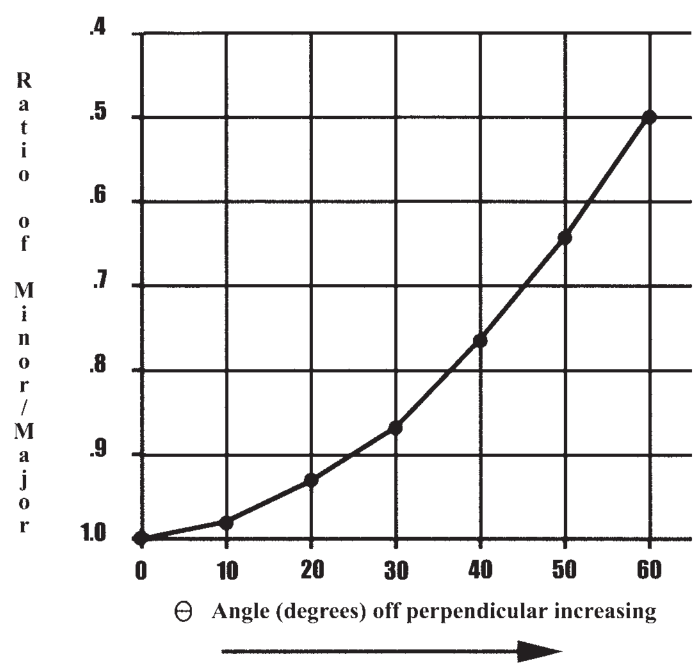

FIG. 4—*Demonstrates the relationship between increasing Theta values and the amount of photographic distortion (ratio of minor/major).*

to duplicate the context of many evidence photographs that are seldom free from perspective and parallax distortion. This intended variability of camera-to-object distance produced "initial" images that were not life-size and would require both digital distortion control and digital resizing (1:1) steps. These images were imported into Adobe® Photoshop® via a ScanDisk® external drive for analysis. A Dell® Dimension XPS T500 computer with a 20 GB hard drive and 256 MB of RAM was used. The use of a digital camera eliminated conventional image capture, film processing, and subsequent scanning steps. The authors do, however, suggest conventional photography be included in actual forensic casework.

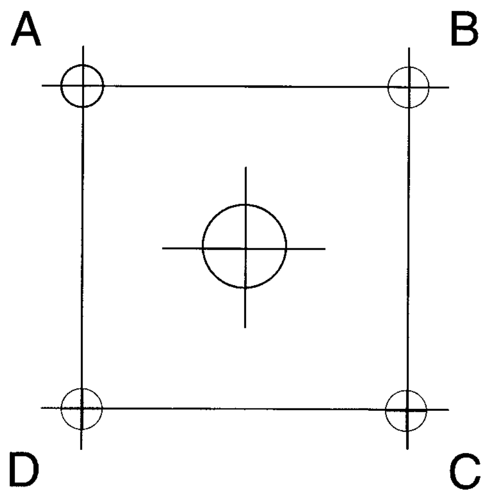

FIG. 5—*A measuring grid of known dimensions was fabricated. The four sides measure 4 cm. each and all internal angles measure 90°.*

Once imported into Photoshop®, the original images were adjusted for contrast, rotated to orient the horizontal leg of the scale along the computer screen's X-axis, and cropped. The sides and internal angles of the grid in each of these six resultant images (theta values of 0, 10, 20, 30, 40, 50) were measured using Photoshop® "Measure Tool."

The scale within the image was then brought back to its original shape using Photoshop's "Distort" function (Fig. 6*a* and Fig. 6*b*). A brief description of the steps involved is outlined below:

1. Use the Measure Tool (keyboard command: U) to rotate the image (top menu command: Image > Rotate > Arbitrary) to align the scale along the X/Y axis.
2. Crop (keyboard command: C) the resultant image to eliminate unnecessary peripheral areas.
3. Bring guides (Top menu command: View > Show Rulers) onto the image and align them along the edges of the scale.
4. Create a perfect circle (in its own layer) for comparison purposes. (Top menu commands: Layer > New, then select Elliptical Marquee Tool, hold down Shift and Alt keys, click and drag cursor. Choose Edit > Stroke, then Select > Deselect.
5. Select the entire image (top menu command: Select > All).
6. Repetitive use of the Distort function (top menu command Edit > Transform > Distort) to align the edges of the scale with the guides.

Since the dimensions or the grids were not life-size, the image was then resized to (1:1). A brief description of the steps involved

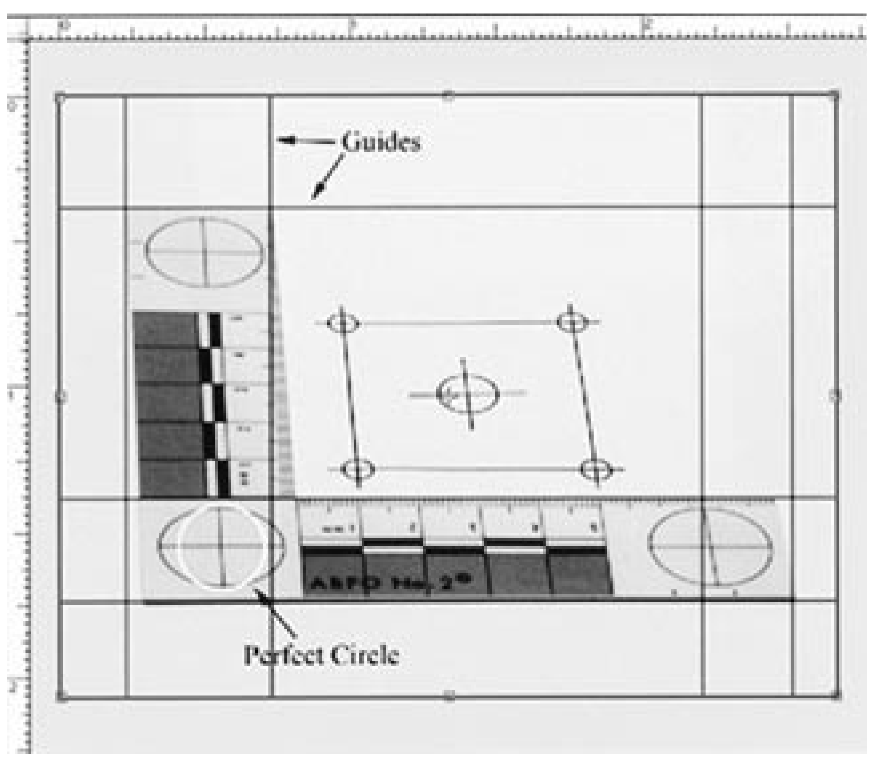

FIG. 6*a*—*Placement of guides along the edges of the scale demonstrates the presence of photographic distortion (Type I). A perfect circle is drawn and superimposed over the scale's circular reference shapes to show distortion is present. Notice the eight anchor points around the perimeter of the image. These are used to bring the scale back to its original shape. After the rectification procedure is accomplished, the image can be resized to life-size (1:1).*

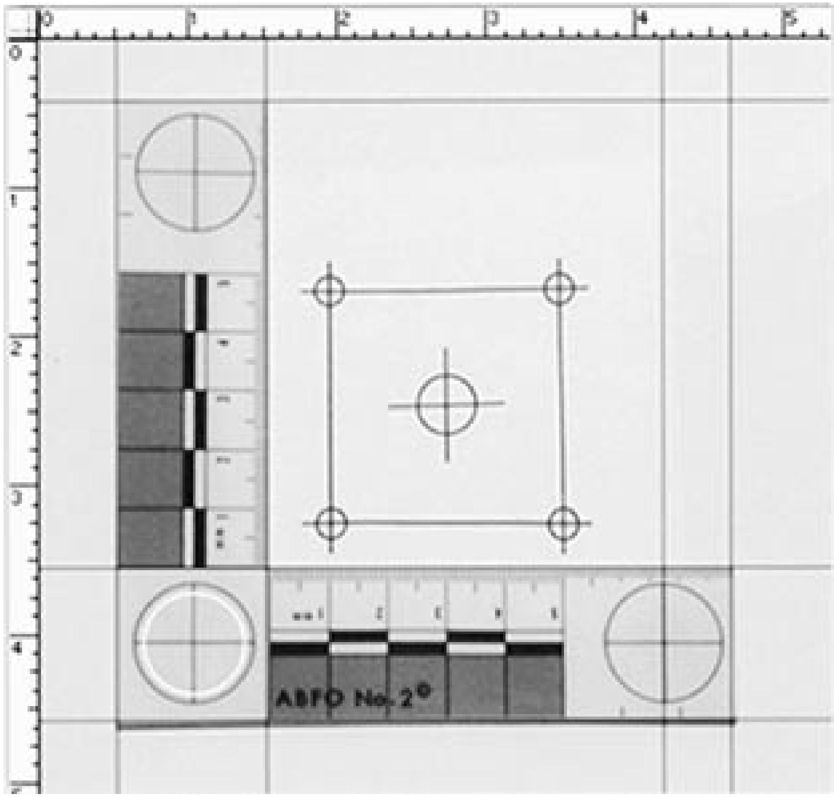

FIG. 6*b—The image has been rectified using the "Distort" function. The legs of the scale are perpendicular, their sides are parallel, and the circular reference shapes are circular not oval. The photographic distortion (Theta) has been eliminated. A more meaningful comparison can now be carried out.*

is outlined below:

1. Measure Tool (keyboard command: U) used to measure the 5 cm increments of the scale's horizontal leg.
2. Info Palette records the dimension of this measurement (D). This would be 5 cm in a life-size image, a lesser value, or larger in an image greater than 1:1.
3. The image's width and height is separately factored by the ratio of 5 cm over the measured dimension of the actual scale (5/D). Top menu commands: Image > Image Size to show dialogue box. Uncheck "Constrain Proportions," then adjust image size values based on the ratio obtained above.

The grid was hidden during these steps through the use of an opaque Layer to ensure blinding of the results during the ABFO No. 2 Scale's rectification and resizing procedures. Once the rectification and resizing procedures were complete, the opaque layer was turned off and the revealed grid was again measured. The internal angles of the resultant images were measured as previously described. The size of the grid was also measured to evaluate the success of the resize procedures.

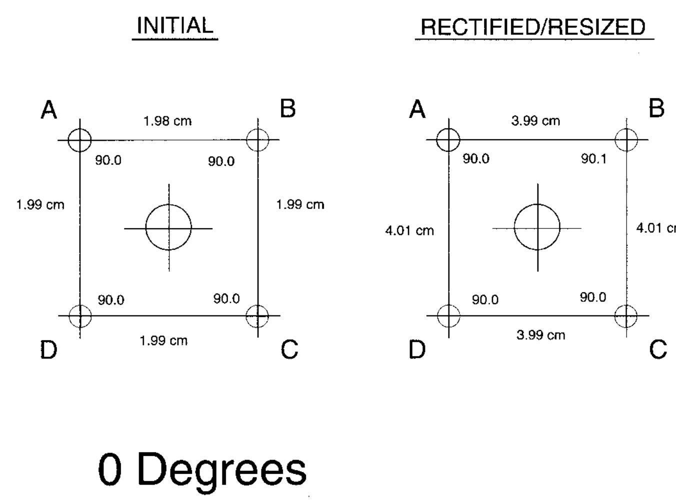

FIG. 7*a—Initial and rectified/resized measurements of the test grid at Theta value of 0°. Both linear and angular measurements are displayed.*

Results

Figures 7*a*–7*f* show results of both the angular and linear measurements. These results are displayed as initial and rectified/resized measurements. The measure tool has the ability to measure angles to within approximately 0.1°. This is the reason, in some instances, the sum of the angles within the grid do not equal 360°.

Angular Measurements

The measurements of each angle (A,B,C,D) within the grid were plotted against theta and displayed in Figs. 8*a*–8*d*.

- Angle A shows initial values very close to 90° at both 10 and 20-degree (theta) camera angles. After 20°, a sharp increase in distortion is observed reaching a maximum deviation of −5.6°

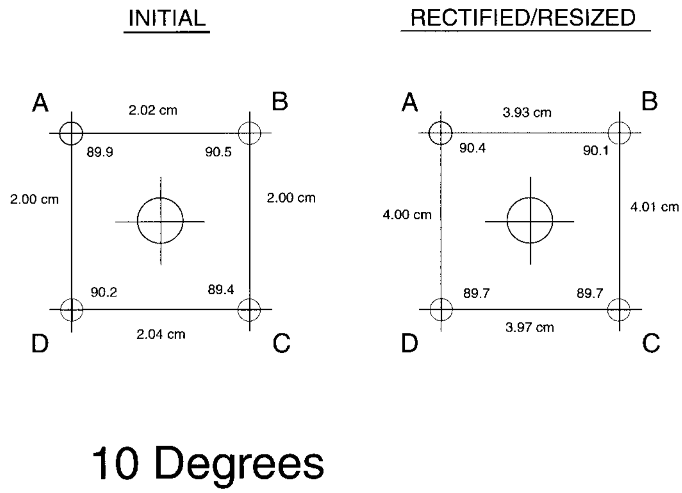

FIG. 7b—*Initial and rectified/resized measurements of the test grid at Theta value of 10°. Both linear and angular measurements are displayed.*

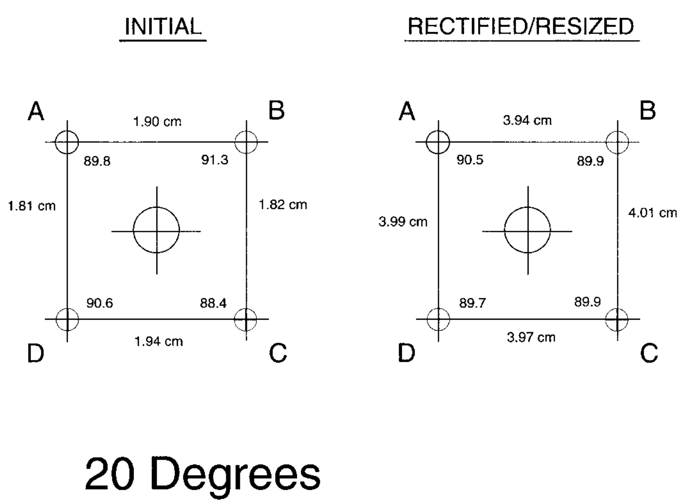

FIG. 7c—*Initial and rectified/resized measurements of the test grid at Theta value of 20°. Both linear and angular measurements are displayed.*

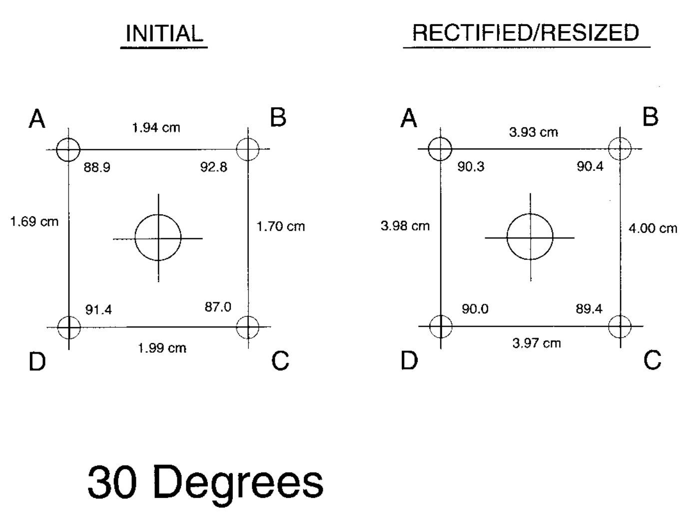

FIG. 7d—*Initial and rectified/resized measurements of the test grid at Theta value of 30°. Both linear and angular measurements are displayed.*

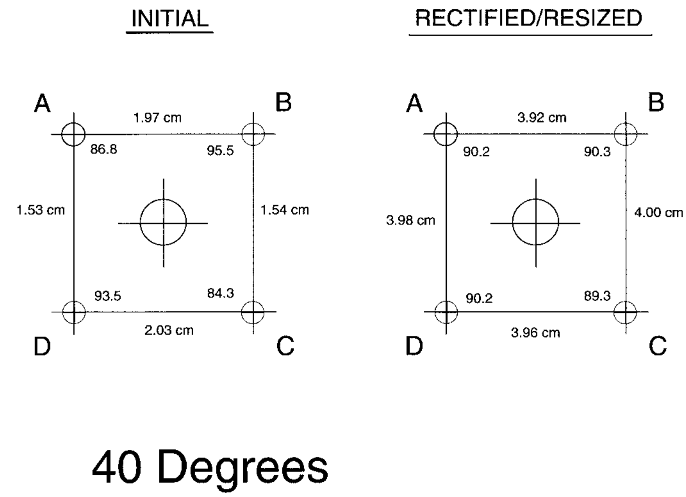

FIG. 7e—*Initial and rectified/resized measurements of the test grid at Theta value of 40°. Both linear and angular measurements are displayed.*

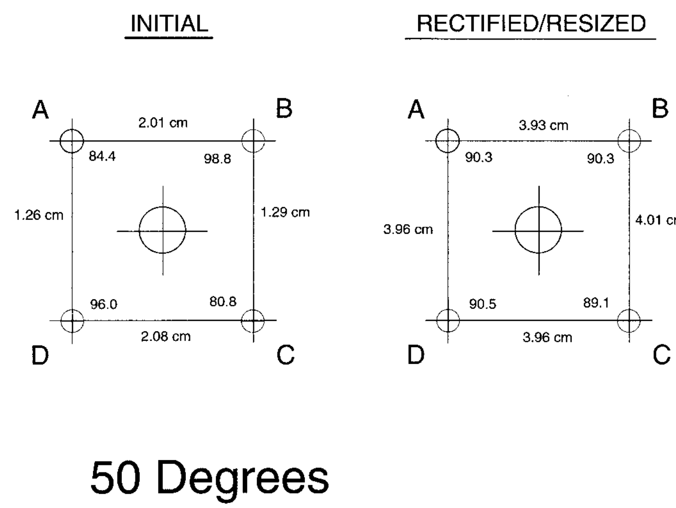

FIG. 7f—*Initial and rectified/resized measurements of the test grid at Theta value of 50°. Both linear and angular measurements are displayed.*

at a theta value of 50°. The digitally rectified values show residual distortion between 0.2 to 0.5°.

- Angle B began to show significant distortion beginning at approximately 5° camera angle. This distortion increases to a maximum deviation of +8.8°. The digitally rectified values for angle B show residual distortion between 0.1 and 0.4°.
- Angle C also began to show significant distortion at theta values beginning at approximately 5°. This distortion increased to a maximum deviation of −9.1°. The digitally rectified measurements show residual distortion from 0.1 to 0.7°.
- Angle D showed significant distortion beginning slightly above a theta value of 5° and continuing to a maximum deviation of +6°. The digitally rectified values show residual distortion from between 0 and 0.5°.

The initial measurements for all five non-perpendicular angles (10, 20, 30, 40, 50°) show a direct relationship to increased theta value. In other words, the angles become more distorted as theta is increased. The exponential relationship indicates that the degree of

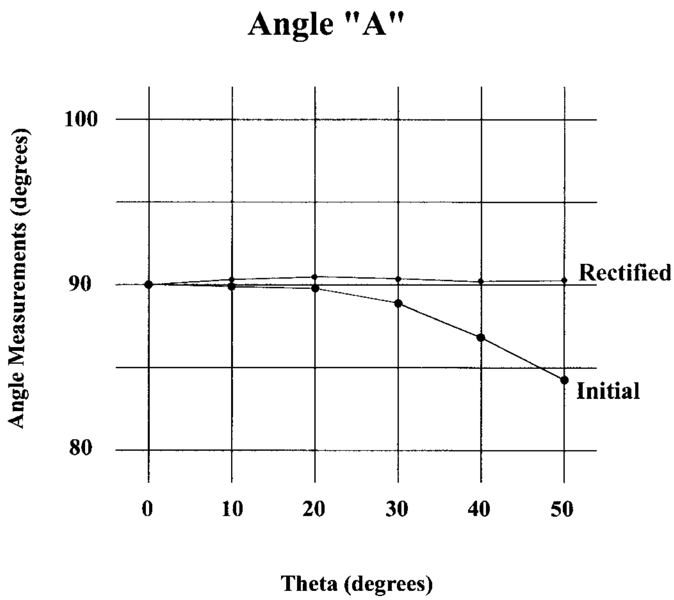

FIG. 8*a*—*Initial and rectified values for angle A at varying Theta values.*

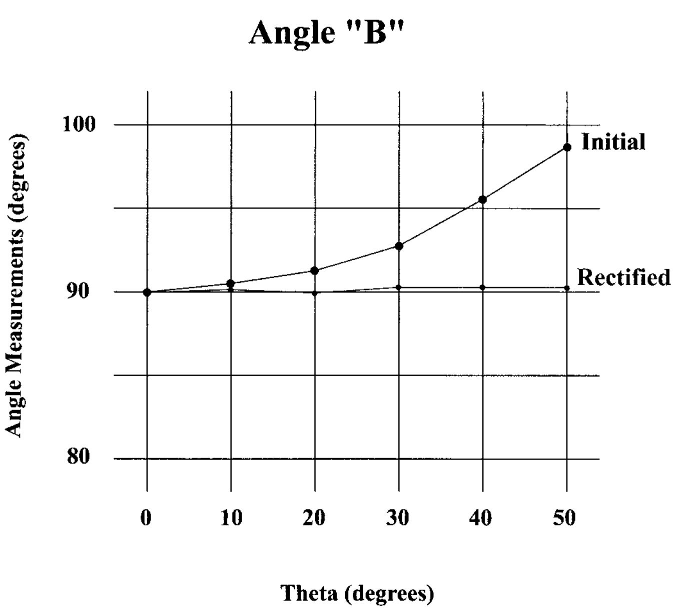

FIG. 8*b*—*Initial and rectified values for angle B at varying Theta values.*

distortion is larger with increasing theta values. After rectification, these angular distortions (Type I) are eliminated.

Linear Measurements

The four sides of the grid were measured after the rectification and resize procedures were performed. These values are displayed in Fig. 9, and ranged from 3.92 cm to 4.01 cm. This represents a maximum of 2% deviation from the actual grid size with the majority of values between 0 and 1%.

Discussion

The initial angular measurements of the distorted grids reflect the amount of photographic distortion caused by improper camera position present within these images. The rectified angular measurements show the degree of correction possible by the digital rectification procedures. The linear measurements of the grids within the digitally rectified and digitally resized images reflect not only the success of the rectification procedures but also the resize procedures.

Distortion of the angular and linear measurements exponentially increases as theta values are enlarged. The distortion threshold appears at theta values of greater than 5°. Marked improvement in measured angular and linear dimensions occurred after digital rectification and digital resizing of the image. The outcome of any pattern analysis, in the face of photographic distortion above 5°, will be flawed without proper remediation by the methods described.

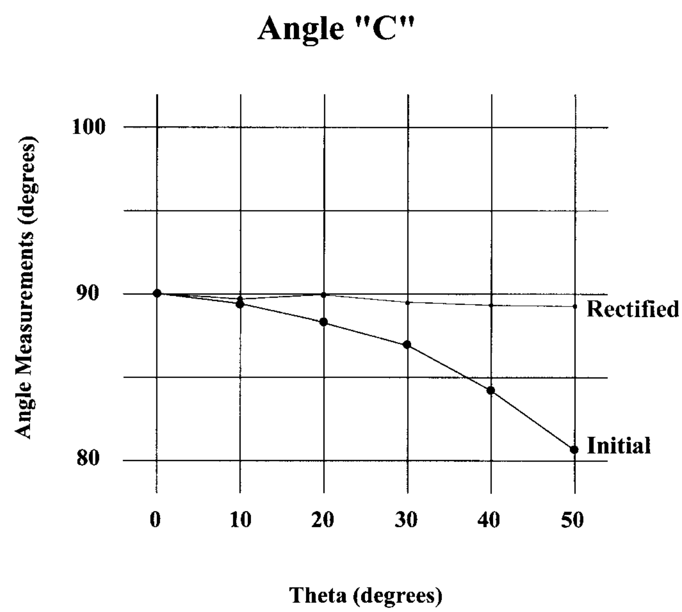

FIG. 8*c*—*Initial and rectified values for angle C at varying Theta values.*

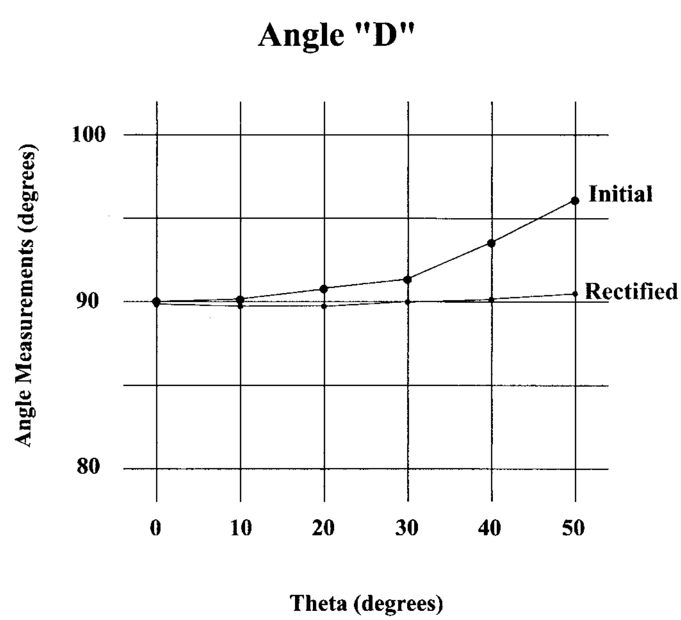

FIG. 8*d*—*Initial and rectified values for angle D at varying Theta values.*

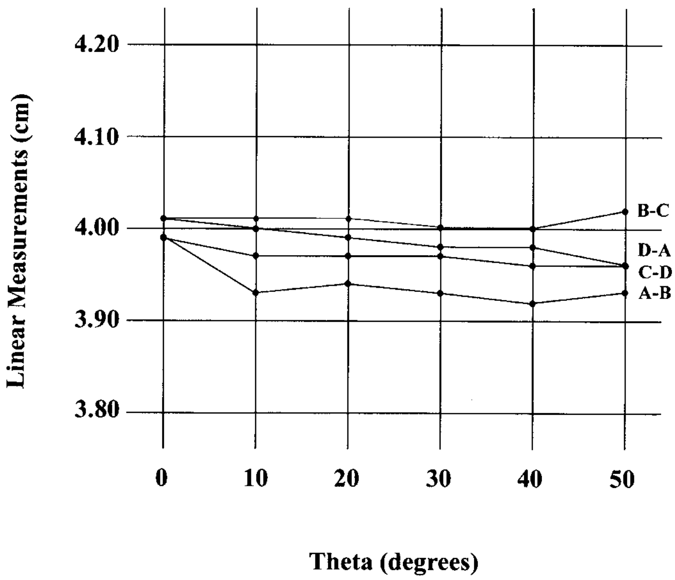

FIG. 9—*Resized linear measurements of grid sides at varying Theta values.*

Uncontrolled dimensional inaccuracy will result from any attempt to use the distorted image for a comparative analysis. The original evidence image without the proper use and sequence of rectification and resize methods will be an inaccurate reproduction of the original object.

Conclusions

In many cases, evidence photographs provided to the forensic investigator for pattern analysis contain some degree of photographic distortion. This distortion must be detected and corrected before a meaningful analysis can be carried out. Failure to correct for distortion will lead to faulty conclusions when the subsequent analysis is performed.

According to this study, rectification and resizing of evidence photographs with Type I distortion can be reliably accomplished by the examiner using Adobe® Photoshop®. Type II parallax distortion is caused by misalignment of the original evidence and the linear scale, and can be corrected only by re-photographing the evidence sample. By inference, Types III and IV distortion, being subsets of perspective distortion (Type I), are amenable to digital rectification and then digital resizing methods. It is imperative that examiners initially review all evidence photographs for various component non-parallel and non-perpendicular features before advancing to any further analysis. All examiners need to look at these images and ask the question, "Is this photograph a fair representation of the actual item of evidence?"

The results show that correction of photographic inaccuracies can be accomplished to within relatively narrow limits. It is the authors' opinion that increased forensic science familiarity with Adobe® Photoshop® capabilities and the digital rectification/resize procedures will lead to better distortion detection and correction. Elimination of these uncontrolled photographic variables should lead to more accurate results and greater confidence in the outcome of pattern analyses.

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11. Adobe Systems, Incorporated, Seattle, WA. Photoshop 6.0 version is currently available.

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