Document Title: Evaluating High Dynamic Range (HDR) Processing with Regards to the Presence of Individualizing Characteristics in Shoeprint Impressions

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Evaluating high dynamic range (HDR) processing with regards to the presence of individualizing characteristics in shoeprint impressions.

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Abstract: Difficult lighting situations that lead to challenging photographic conditions are common at crime scenes. It is imperative that the photographer accurately documents the scene details despite vast differences between the brightest areas and the darkest shadows. High Dynamic Range (HDR), unlike painting with light, is a method for processing a series of photographs into one image that captures the fullest range of highlights and shadows present in the original impression. HDR is a method used to increase the span between shadows and highlights in an image by taking more than one picture of the same scene – shots that maximize shadows, maximize mid-tones, and maximize highlights – and then merging them into one unified picture with tremendous tonal range. This research found that HDR processing of multiple images does not produce a significant increase in detailed information compared with viewing the same images in Photoshop. However, exposure (auto)bracketing increases the ability to capture more detailed images of footwear impressions than a single image alone, and allows the use of HDR software for rapid processing and comparison.

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Introduction

The ease and accuracy with which the laboratory is able to analyze footwear evidence is largely determined by the quality of the evidence collected in the field. If crime scene personnel have the capability of capturing images that more closely resemble the true nature of the evidence in terms of depth, contrast, and detail, then the time spent correcting and re-processing the images by the footwear examiner will be minimized. The footwear examiner will be better equipped to justify their conclusion, will be able to do so with a higher degree of certainty, and will do so with increased ease and efficiency. Having quality data with which to make informed and reliable conclusions will help to expedite footwear analysis from evidence recovery to reporting.

HDR processing has the potential to be useful to all impression evidence examiners, especially for those who perform the bulk of their analyses on-screen. HDR processing uses multiple exposure-bracketed source images. Using a camera's auto-bracketing feature to capture impression evidence provides more useable evidence photographs. Auto-bracketed source images provide the footwear examiner with multiple processing options, as well as capturing additional information that might not have been captured in a single image alone. This is especially true when the evidence cannot be properly lit, or it contains glare or reflection.

Dynamic range is the ratio between the maximum and minimum luminance values of a physical measurement. The definition can change slightly depending on if the dynamic range refers to a scene (lightness to darkness), a camera (saturation to noise), or a display (highest and lowest intensities emitted). High Dynamic Range (HDR) imaging is achieved by merging multiple photographs, which are individually referred to as Low Dynamic Range (LDR) photographs. HDR imaging is a process, not an end product. It is the use of a mathematical algorithm that combines luminance values between the lightest and darkest areas of an image. By combining images, a more accurate representation of the range of intensity levels can be achieved.

In order to more closely reproduce the highlights and shadows of an original scene as the human eye sees it, the amount of information in an image ("bit depth") must be increased. However, 24-bit HDR images present considerable difficulty in photography in that they cannot be displayed correctly on standard display devices like monitors and printers, which can only reproduce a low range (16-bit or 8-bit images). In order to compress the shadows and highlights into an 8-bit image, the HDR image must be *tone mapped*. Tone mapping consists of a variety of algorithms used to compress the 24-bit information differently, depending on the desired outcome. How is this done? There are a total of 256 tonal or color values in a histogram. In order to increase the contrast of a single image, the histogram must be altered. This alteration results in empty channels, called "combing". When HDR is used, there is additional information available from the combined images. This information can be "filled into" the histogram when tone mapping, resulting in an image with 256 color values, increased contrast, *and* no combing or loss of information. A tone mapped image is not an HDR image because it no longer represents the original values of light captured. Rather, it *reproduces* the dynamic range captured so the image can be viewed on standard monitors or prints.

Materials and Methods:

The footwear chosen for this study displayed a significant number of unique marks obtained from normal daily use. Ten individualizing characteristics were designated on each of two different worn-out athletic shoes (Brooks and Puma) that showed a variety of edge characteristics, depths, sizes, contours, and textures that would be similar to marks seen in casework. These unique identifying marks were graded from A (easy to see) to C (difficult to see), based on their ability to be visualized on the outsoles (Figs.1& 2). Three-dimensional impressions provide greater photographic challenges than two-dimensional impressions. Therefore, three-dimensional impressions (the worst-case scenario) were chosen for this study. In order to minimize substrate variables, clay impressions were made using each of the athletic shoes (Figs. 1a & 2a). These exemplars were made in order to compare the quality of a unique mark in a single photograph to that same mark in a photograph processed with HDR**.** The impressions were photographed in full sun using a Nikon D700 DSLR camera with ISO 200 at f/11 and 1/500s shutter speed. The impressions were then placed in half light and half shadow to simulate unfavorable lighting conditions, and photographed using both the Nikon D700 DSLR camera with tripod and the Nikon Coolpix P5100 point-and-shoot camera with tripod. Both cameras were set to aperture priority and programmed to auto-bracket by adjusting the exposure (without flash) with varying shutter speeds. The Nikon D700 produced a series of 9 RAW (12-bit) and JPEG (8-bit) photographs at increments of 0.5 eV exposure, over a total range of 2 stops in either direction from "ideal" (4 stops total). The Nikon Coolpix took a series of 3 JPEG photographs at increments of 1.0 eV exposure, over a total range of 1 stop in either direction from "ideal" (2 stops total). This produced a bracketed series of original photographs with varying exposures. Selected photographs from this series were processed using High Dynamic Range (HDR) software. Other photographs from this series were processed using simple digital editing techniques commonly used in the laboratory for the examination of footwear. The HDR images were compared to the original images as well as the digitally edited images (see examples). Several "ideal" footwear photographs were also taken using oblique light. These were also available as reference photographs for comparison purposes. Green arrows were used on the photos to indicate marks that could be used for identification; red arrows were known identifying marks that could not be sufficiently visualized in the photo to be used for identification purposes.

Original Outsole (image inversed)

Fig. 1

Original Impression in Clay

Fig. 1a

Original Outsole (image inversed)

Fig. 2

Fig. 2b

Software Programs

The following software applications contain a variety of tone mapping algorithms that produce images for various end uses. The algorithms used in this study were chosen for their ability to produce realistic images (i.e., no excessive tone mapping), and their usefulness was compared with respect to the objectives of this project.

Picturenaut HDR Software is free, offers an auto-align feature, and produces realistic images. The software lacks the options available to create a "dynamic look" to the final image, but that is of no concern for this application. Instead, the lack of options makes for an easy-to-use, straightforward process.

Photomatix Pro HDR Software is the most popular option on the market. It is reasonably priced, easy to use, and produces realistic images. This software has a problematic auto-align feature, but gives greater control over the tone mapping process than Picturenaut, and was the best choice for producing detailed, realistic images overall.

Photoshop CS5 is the most expensive option. Its HDR capabilities not only offer an auto-align feature, but also a large selection of options for processing. It creates realistic images, but the end result is often not as useable or aesthetically pleasing as that of Photomatix.

Even with an impression that has an abundance of individualizing marks, proper lighting could make the difference between a determination of "identification" and simply an "inclusion." Depending on the number and quality of the photographs captured at the scene, the footwear examiner is then faced with a number of choices.

A single image:

Unfortunately, a photographer might capture only one, poorly-lit footwear impression at the scene. When this is the case, true HDR is not possible. However, several editing options can be used to improve clarity and contrast, ultimately providing a photograph that can be examined for similarities in pattern, size, wear patterns, and individualizing characteristics.

Simple processing was done by using Photoshop CS5 to edit the photographs (Fig.3). Raw images were opened using the 16-bit setting. After a new *levels adjustment layer* was created, clicking on the *layer mask* thumbnail in the adjustment layer allowed choosing the *gradient* tool from the toolbar and adjusting the mask accordingly. The white and black point levels for the image were adjusted to meet each end of the histogram to create the best possible image.

Best RAW format image with levels adjustment

Fig.3

Two overlaid images:

Two photographs were selected from the series of original images to illustrate other processing options if two poorly lit, but complementary photographs of the same shoe impression exist. This might happen if the oblique lighting is too bright, too close to the print, or if the impressions are taken under uneven lighting conditions. When two photographs can be sufficiently overlaid (manually or by using the *auto-align* feature), the images can be "stacked" on top of each other, and selectively *masked* or *deleted* to show only the best areas of each image. Although these processes are not true HDR either, they can be useful to the footwear examiner.

This simple editing was performed using Photoshop CS5 in the 16-bit setting. Three general techniques were used: 1) overlay with *blending mode* 2) *layer mask* with *gradient* and 3) *erase with feathering.* For these techniques, two complementary image layers were perfectly "stacked" on top of each other manually using the *Edit>auto-align* feature, or holding the shift key when overlaying the two photographs. (Note: The overall appearance of the resulting image will be determined by the image layer sequence.)

Overlay with blending mode: Once the photographs were stacked, the "top" image was selected and a blending option was chosen from the pull-down menu by scrolling through the different modes. Changing the *opacity* of the same layer provided an additional adjustment option (Fig. 4).

Layer mask with gradient: After the photographs were stacked, a *layer mask* with *gradient* was added to the "top" image to even out bright spots and lighten shadows (Fig.5).

Erase with feathering: Similarly, selecting the *marquee* tool and clicking *delete* was used to select the area that should be erased, allowing portions of the complementary photograph to be seen. *Feathering* the selection blended the edges with the complementary photo.

Photoshop - 2 images layered, with partial opacity

Fig.4

Photoshop - 2 images layered, with gradient erase

Fig.5

<u>*Three or more images:*</u>

HDR processing can be done when three or more photographs are captured using a tripod and a wide range of exposures. The human eye has far greater tonal range, color depth, and dynamic range than a camera. The goal of the HDR process is to create an image that more closely approximates what the human eye can see of the original evidence. HDR processing involves combining several selectively exposed footwear images, and merging them into a single image. This provides a much greater tonal range compared with a single traditional low dynamic range image. By capturing the lightest highlights and the darkest shadows of the scene, one cohesive image can be produced that will theoretically display the best areas of each individual source image while still retaining all of the detail and image quality. It should be noted that none of the original source images was able to capture all of the content and detail of all ten individualizing marks in one photograph. However, HDR processing was able to do so. The relative success of HDR processing relied on taking a large number of bracketed images over a wide exposure range. HDR processing was accomplished in the following ways:

Picturenaut (Fig.6): Click *File>Generate HDRI* and *add* the desired photographs and click *OK*. Click *Image>Tone mapping* to choose one of four preset tone mapping algorithms: Bilateral (contrast and saturation adjustments), Exposure (exposure and offset adjustments), Adaptive Logarithmic (exposure, bias, shadow luminance, and contrast adjustments), and Photoreceptor (exposure, dynamic compression, saturation, and contrast adjustment). Since each lighting situation is unique, one specific preset algorithm will not work for every situation. Each preset algorithm also allows for manual adjustment of the image so the user can fine-tune the final image as necessary. Once the tone mapping is completed, the image can be saved and printed.

Picturenaut HDR software using 3 source images

Fig. 6

Photomatix Pro 4 (Fig.7): Select the *Load Bracketed Photos* button, select the desired photographs and click *OK*. Choose the desired preprocessing options (including image alignment, ghost removal, and noise reduction). The *Tone mapping/Fusion* button offers two processing options: Tone mapping (which offers versatile adjustment options for a wide range of lighting conditions), and Exposure Fusion (which generates a more natural look with noise reduction). Two toning methods are also present. A wide range of preset algorithms is available, the results of which are conveniently displayed as thumbnails at the bottom of the screen. Numerous manual adjustments are on hand for each of the preset options to allow fine-tuning of the image as desired. Click the *Process* button, then save and print the final image.

Photomatix offers a significant number of additional tools, including the ability to save preset adjustment settings, and adjust a batch of photographs. A tutorial button is located on the home page, and the help options are comprehensive and easy to understand.

Photomatix HDR software using 3 source images

Fig. 7

Photoshop CS5 (Fig.8): Select the *Mini Bridge* tab in the upper panel in Photoshop, and select the desired photographs. Click the *Tools* icon (a rectangle with an arrow) in the upper right side of the toolbar. Select *Photoshop>Merge to HDR Pro*. The original source images are shown as thumbnails across the bottom of the screen. The source images can be selected or unselected, offering the ability to compare the effects of including or excluding source images and removing ghost (out-of-focus or misaligned) images. Several tone mapping presets and toning methods are available in the preset pull-down menus. If any additional manual adjustment is necessary, the preset will automatically switch to "Custom" setting, allowing the user to effect specific changes. When the desired tone mapping effect is achieved, click *OK*. The image can be saved and printed.

Photoshop offers the most extensive number of tools available for image enhancement, and the ability to pre-process or post-process images without having to switch between software programs. An extensive array of tutorial material is available online.

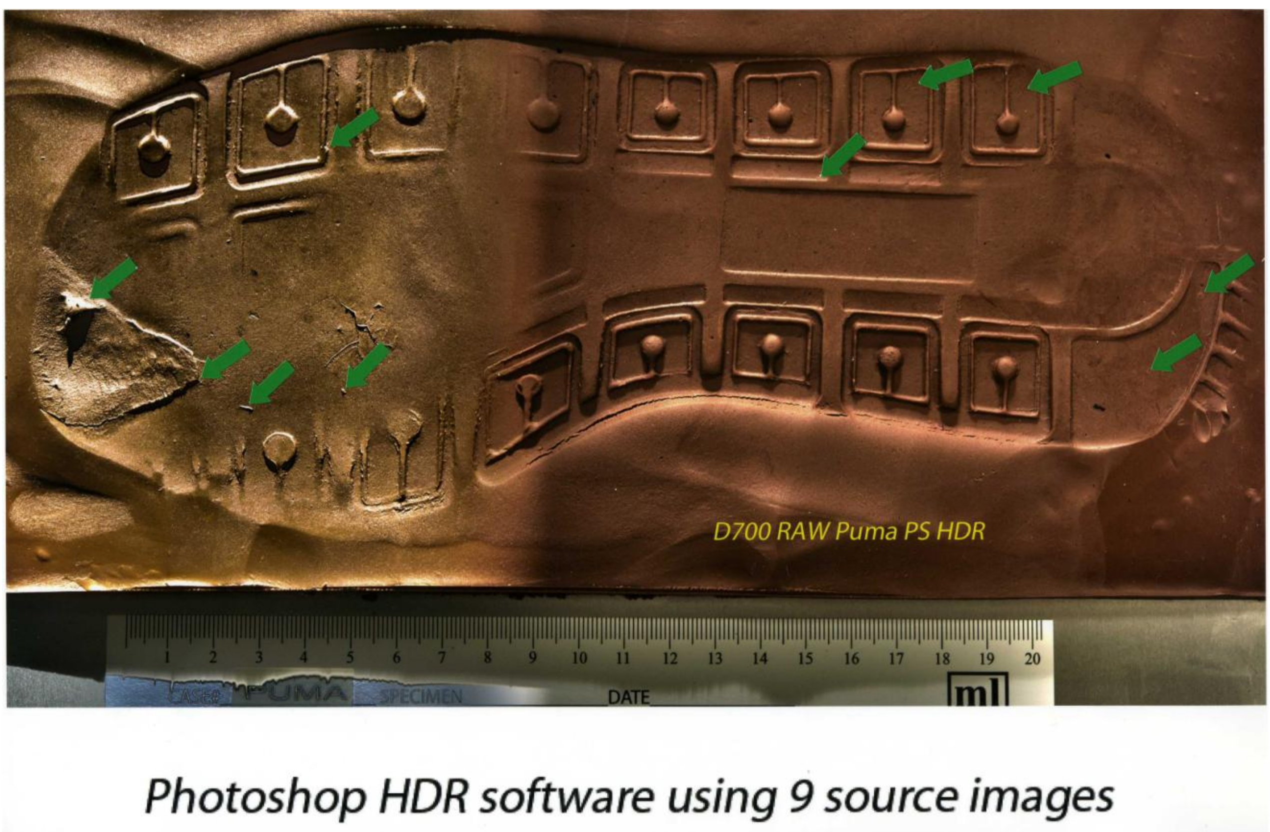

Fig. 8

Results:

Ten individualizing characteristics were originally defined on the right outsole of the Puma athletic shoe, and graded by letter (A-C) on the basis of ease of visualization. Marks #9 and #10 were relatively easy to identify visually as individualizing features in the shoe outsole, and in the original impression in clay. Marks #1, 4, 7, and 8 were more challenging to identify, and marks #2, 3, 5 and 6 were difficult to visualize and identify because of their size, depth, or location. With proper oblique lighting from four directions, all of the individualizing marks could be seen in the original impression. However, only eight out of ten individualizing marks were identifiable in any *single* photograph of the original impression in clay. As expected, the original bracketed source images of the impression in shadow were only able to capture about 50-80% of the identifying marks at one time. When the original bracketed source images were edited, however, the results improved. Simple editing of a single image with Photoshop was able to define seven out of ten individualizing marks. Simple editing of two complementary images was able to define all of the marks. HDR-processing was able to define between 50-100% of the individualizing marks, depending on the software and the number of original source images used.

***Table 1* -** Puma Impression in Shadow

	1 (B)	**2 (C)**	**3 (C)**	**4 (B)**	**5 (C)**	**6 (C)**	**7 (B)**	**8 (B)**	**9 (A)**	**10 (A)**
Photo 5209					**x**	**x**	**x**	**x**	**x**	**x**
Photo 5210						**x**	**x**	**x**	**x**	**x**
Photo 5211						**x**	**x**	**x**	**x**	**x**
Photo 5212						**x**	**x**	**x**	**x**	**x**
Photo 5213						**x**	**x**	**x**	**x**	**x**
Photo 5214	**x**				**x**		**x**	**x**	**x**	**x**
Photo 5215	**x**	**x**	**x**	**x**	**x**		**x**	**x**	**x**	
Photo 5216	**x**	**x**	**x**	**x**	**x**			**x**		
Photo 5217	**x**	**x**	**x**	**x**	**x**			**x**		
Photoshop HDR using 3 images						**x**	**x**	**x**	**x**	**x**
Photoshop HDR using 9 images	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Photomatix HDR using 3 images	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Picturenaut HDR using 3 images	**x**					**x**	**x**	**x**	**x**	**x**
1 image Photoshop levels adjustment	**x**	**x**				**x**	**x**	**x**	**x**	**x**
2 images Photoshop layer mask	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
2 images Photoshop blend mode						**x**	**x**	**x**	**x**	**x**

Ten individualizing characteristics were originally defined on the right outsole of the Brooks athletic shoe, and graded by letter (A-C) on the basis of ease of visualization. Marks #3, #5, #6, #9 and #10 were relatively easy to identify visually as individualizing features in the shoe outsole, and in the original impression in clay. Marks #1, 4, 7, and 8 were more challenging to identify, and marks #2, 3, 5 and 6 were difficult to visualize and identify because of their size, depth, or location. With proper oblique lighting from four directions, all of the individualizing marks could be seen in the original impression. However, only eight out of ten individualizing marks were identifiable in any *single* photograph of the original impression in clay. As expected, the original bracketed source images of the impression in shadow were only able to capture about 50-90% of the identifying marks at one time. When the original bracketed source images were edited, however, the results improved. Simple editing of a single image with Photoshop was able to define ten out of ten individualizing marks. Simple editing of two complementary images was able to define all of the marks. HDR-processing was able to define between 50-100% of the individualizing marks, depending on the software and the number of original source images used.

Table 2 - Brooks Impression in Shadow

	1 (C)	**2 (B)**	**3 (A)**	**4 (B)**	**5 (A)**	**6 (A)**	**7 (C)**	**8 (B)**	**9 (A)**	**10 (A)**
Photo 5200		**x**	**x**		**x**	**x**	**x**	**x**	**x**	**x**
Photo 5201					**x**	**x**	**x**	**x**	**x**	**x**
Photo 5202					**x**	**x**	**x**	**x**	**x**	**x**
Photo 5203					**x**	**x**	**x**	**x**	**x**	**x**
Photo 5204			**x**		**x**	**x**	**x**	**x**	**x**	**x**
Photo 5205	**x**	**x**	**x**		**x**	**x**	**x**	**x**	**x**	**x**
Photo 5206	**x**	**x**	**x**	**x**	**x**	**x**		**x**	**x**	**x**
Photo 5207	**x**	**x**	**x**	**x**	**x**	**x**		**x**		
Photo 5208	**x**	**x**	**x**	**x**	**x**	**x**				
Photoshop HDR using 3 images		**x**	**x**		**x**	**x**	**x**	**x**	**x**	**x**
Photoshop HDR using 9 images	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Photomatix HDR using 3 images	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Picturenaut HDR using 3 images	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
1 image Photoshop levels adjustment	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
2 images Photoshop layer mask	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
2 images Photoshop blend mode	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**

Conclusions and Discussion:

HDR processing of bracketed footwear photographs was a surprisingly easy and straightforward tool for image processing, but did not always provide the significant increase in detailed information that was expected. The number of bracketed original source images used, the type of software, and the nature of the individualizing marks all played significant roles in whether an identification could be made.

A large number of bracketed, original source images over an extended range of exposure values provided the best possible outcome for processing with HDR software. RAW format provided the greatest ability to visualize small details on-screen. Although not an ideal format, bracketed JPEG images also showed marked improvement in the level of available detail over a single photo. In addition, many of the options for tone mapping and post-processing were highly subjective. Simple editing of bracketed photos without the use of HDR produced the most aesthetically pleasing image overall for court purposes while still retaining all of the detail in the original photographs. Only Photomatix produced an overall image of comparable aesthetic value.

The usefulness of exposure-bracketed images cannot be overstated. Capturing even three exposure-bracketed photos provided additional information about the footwear that would have otherwise been lost. When a poorly lit footwear impression was captured using a bracketed series of images, detail could be recovered with ease in both the deepest shadows and the brightest highlights. In practice, exposure bracketing and HDR processing was also able to overcome many other difficult lighting issues on two-dimensional surfaces. These included reflections and glare on polished or tile floors and surfaces, flash hot spots, mottled shadows, and difficult contrast situations. This technique effectively provided the examiner with sufficient detailed information in the source images to provide an identification.

It is important to remember that the application of HDR to footwear impression photography does not allow for the identification of individualizing characteristics above and beyond that which the original images provide. RAW format captures the most digital information possible in the original images. JPEG format is acceptable only if the photographer can guarantee a perfect photograph every single time. Since this is simply not realistic, RAW format should be standard for comparison-quality photographs. This is critical because any improperly exposed digital image will lose detail in both the shadowed and highlighted areas. Since RAW images contain significantly more bit-depth information (i.e., how each pixel expresses color) than JPEG images, this additional information makes detail recovery possible in RAW format that would not be possible in JPEG format. HDR images contain more bit depth information than any single image, allowing for far greater adjustment of contrast and color saturation without alteration of the image or loss of information.

HDR was capable of producing increased tonal range to the same degree over the entire image, but produced only a marginal increase in contrast in the most difficult-to-see features. Since the HDR algorithm introduced unknown variables into the processing workflow, it was important to weigh this aspect against the benefits of the resulting images. After analysis of the

HDR images, it was determined that HDR was a powerful and useful tool in terms of its efficiency and degree of image enhancement for the visualization of unique features on-screen. Of note, there is an important difference between using these tools to temporarily help visualize a unique mark on-screen, and using these tools for the ultimate identification of that mark from the original source images. The most professional and ethical conclusion of identification is always one that is based on the comparison of unaltered original photographs. If an image detail seemingly exists on-screen that cannot be seen in any of the original source images, the information should be considered unreliable and no conclusions should be drawn regarding that mark. If, however, the tools for on-screen analysis are used as a way to locate, differentiate, or further justify the existence of a feature already established in the original source photos, the examiner may use this type of "refining" tool to better understand and characterize the nature of the mark. Because of the speed, efficiency and accuracy with which on-screen comparisons can be done, this comparison method will undoubtedly be seen in the futures of most comparative analysis disciplines.

For this reason, if difficult lighting situations, limited equipment, time constraints, or resources pose a challenge at the crime scene, use the auto-bracketing feature. Auto-bracketing over a large exposure range is now available on many digital cameras. This will provide a quick, straightforward, and forgiving means of capturing the "best image" possible in the form of multiple source images.

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Dissemination of Research Findings:

1) Poster presentation at the International Association of Identification, Milwaukee, WI; August, 2011.
2) Speaking engagement at the California Association of Criminalists – Southern California Trace Evidence Study Group Meeting, Los Angeles, CA; January, 2012.
3) Submission of draft article to the Journal of Forensic Identification (a bi-monthly publication of the International Association of Identification) expected March, 2012.