



Assessing and Achieving Accuracy in Digital Dental Photography

STEPHEN R. SNOW, DDS

ABSTRACT Accurate digital photography is becoming part of the standard of care for diagnosis and documentation in dental treatment. Proper exposure and color rendering are critical elements in the capture of useful images with excellent representational quality. Reliable photographic techniques must be consistently applied as a repeatable protocol to create an accurate record of pretreatment conditions and post-treatment results. Every software process that alters an image will degrade the pixel content and should be minimized or avoided.

AUTHOR

Stephen R. Snow, DDS, is visiting faculty, University of California, Los Angeles, Center for Esthetic Dentistry, Los Angeles; is on faculty, Esthetic Professionals, Woodland Hills, Calif.; and in private practice emphasizing cosmetic restorative dentistry in Danville, Calif.

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Excellence in cosmetic dental treatment procedures involves commitment and control. Proper diagnosis, prudent treatment planning, and careful application of proven principles in dental procedures are all required to achieve predictable results and meet patient expectations. Evaluation of photographic images is an indispensable part of the decision-making process.¹ Dental photography for medicolegal documentation, enhanced communication, clinical self-assessment, procedural illustration, and practice promotion provides an essential adjunct to treatment in the progressive dental practice.^{2,3}

The American Academy of Cosmetic Dentistry has published *Photographic Documentation and Evaluation in Cosmetic Dentistry: a Guide to Accreditation Photography* to demonstrate the desired

results of proper photographic documentation.⁴ It contains recommendations for perfecting both magnification and alignment in dental photography. While this guide defines concepts and conventions for the composition of excellent dental images, consistent magnification and alignment by themselves are not enough. If the quality of an image is poor, the difference between initial clinical findings and final results may not be distinguishable. Additional criteria photographic images must meet to be useful and diagnostic.⁴ Excellent photographic images must also have accurate exposure, accurate color, and accurate tonal range.⁵ This article will explore the principles of these criteria and their interrelation as they pertain to intraoral photography with a digital single-lens reflex, DSLR, camera in dental imaging applications.



FIGURE 1. An overexposed image shows loss of highlight detail due to similarity of adjacent light tone pixels.



FIGURE 2. An underexposed image (of the same dentition shown in Figure 1) shows a loss of shadow detail due to similarity of adjacent dark tone pixels.



FIGURE 3. An ideal exposure (of the same dentition shown in Figures 1 and 2) displays discernable detail apparent throughout the image due to visible differences between adjacent pixels in the entire tonal range.

Accurate Exposure

In human vision, light enters the eye through a lens and is focused on the retina. The rods and cones within the retina are stimulated to convert and transmit the light energy to the brain for processing. The brain continually assembles the data into an image for interpretation and subsequent response. In digital photography, light enters the camera through a lens and is focused on a sensor. The electrodes within the sensor are stimulated to convert and transmit light energy data to an internal processor. The processor assembles the data collected by the sensor into an array of colored dots that collectively make up the final image. Each dot of color represents one picture element called a pixel.²

Precise photographic replication of the appearance of teeth requires accurate exposure.⁶ Cameras are designed to mimic the abilities of the human eye in viewing light or dark objects in a variety of lighting conditions. The sensor and processor inside a digital camera, however, are not nearly as flexible as the human retina and brain in collecting, sensing, and interpreting light. The dynamic range — the difference between the darkest tone and the lightest tone that can be discerned simultaneously — is much more restricted in a camera. The amount of light entering the lens of the camera must be carefully controlled to ensure it does not exceed the limits of this range.

If too much light enters a camera,

the image can be overexposed (**FIGURE 1**). In this case, adjacent pixels of light tones will be identical and highlight details will be indistinguishable. If too little light enters a camera, on the other hand, the image can be underexposed (**FIGURE 2**). In this case, adjacent pixels of dark tones will be identical and shadow details will be indistinguishable. An ideal exposure has discernable detail throughout the image (**FIGURE 3**). Adjacent pixels of all tones are all different throughout the image. Exposure accuracy should always be the highest priority of any photographer capturing any subject.^{2,6}

Intraoral dental photography usually requires the use of a flash as a supplemental light source to overcome the dynamic range limitations of a camera in dental applications.^{2,3} The flash casts light into areas of the mouth that would otherwise be hidden in shadows. When the clinician presses the shutter release on the camera, several events occur in rapid succession that coordinate the internal mechanisms of the camera with the flash burst to capture an image. A circular array of thin baffles moves inward from the outer sleeve of the lens toward its center to reduce the size of the iris through light will enter the camera. The size of the hole through which light passes is called the aperture of the lens.

Subsequently, a curtain covering the light-sensing computer chip (digital sensor) in the camera slides off to one side and out of the way to reveal the sensor,

allowing light to strike its electrodes and initiate the image exposure. The curtain, or shutter, and the length of time it is open is known as the shutter speed. Finally, the flash strobe fires to intensify the light falling on the scene for the image exposure. At the conclusion of the exposure, the flash burst terminates, the shutter closes, and the aperture blades retract back to the sides of the lens.

These mechanical and electronic steps must be carefully synchronized to create a proper photographic image. The aperture must partially narrow before the shutter is opened and the shutter curtain must be open before the flash strobe fires. The shutter speed is necessarily much longer than the flash burst. Manufacturers of contemporary DSLR cameras typically synchronize a flash photograph capture with a shutter speed of 1/60-1/125 of a second. Although that time frame may seem very fast, the order of magnitude of the flash burst speed is typically about 10 times faster.

There are four factors that control the exposure in flash-assisted dental photography: the aperture opening (f-stop), the length of the flash burst, the distance from the camera to the subject, and the sensitivity of the media (ISO).⁶ Shutter speed does not affect the exposure in flash-assisted dental photography because it is coordinated with the flash burst. It is the length of the flash burst and not the length of time the shutter is open that determines the true speed



FIGURE 4. A macro lens can ensure consistent diagnostic magnification and repeatable exposure distance for dental intraoral photography if the clinician selects the manual focus mode (MF) and then selects a desired magnification ratio in the indicator window.



FIGURE 5. The exposure selector wheel of the Canon 30D DSLR is set to manual (M) mode (see green arrow). All other settings represent different TTL (through the lens) exposure strategies that automatically set some (or all) of the camera's exposure controls.



FIGURE 6. An incident light meter can be utilized to measure the intensity of light falling on its sensor. The digital display identifies the proper aperture setting for a perfect exposure with the available light at that working distance, in this case, f32. (See green arrow).

(i.e., time) of these intraoral exposures.⁷

The photographer must determine how those four factors will be selected and set. Exposure control always requires light metering — a measurement of the amount of available light — and subsequent camera setting for proper exposure. The photographer can elect to allow the camera to measure light and determine exposure settings automatically or to perform that measurement and determination manually.^{2,6}

Since a higher ISO often creates unwanted speckled artifacts known as “noise,” the sensor sensitivity is typically set by hand to a low value and left untouched for all subsequent dental exposures. A constant ISO value of 200 is often ideal for intraoral purposes. Additionally, diagnostic dental photography requires that the working distance from the camera to the subject should be a repeatable constant to ensure that any dimensional differences noted between pretreatment and post-treatment images can be attributed only to clinical procedures rather than to inconsistent photographic technique.⁶ To achieve a constant working distance, the lens must be set to manual focus mode, and the clinician must manually select a specific and consistent magnification ratio for each desired view^{2,6} (FIGURE 4). The remaining variable factors that can affect the amount of light in dental photography therefore are the aperture and the length flash burst.^{2,6}

To control these last two variables, current camera systems often incorporate TTL metering — a light monitoring system that measures the amount of light entering through the lens to automatically time the flash burst, set the aperture opening of the lens, or both.² Unfortunately, the amount of light entering the camera is partially dependent on the reflective optical properties of the subject that is being photographed.^{2,6} To automatically calibrate a camera exposure, TTL programming assumes that a significant proportion of the content of each image corresponds to subjects that reflect medium brightness levels of light.^{2,6}

This system works well if sources of midtone luminance such as a medium blue sky or green grass fill a substantial portion of the scene. When photographing a scene that contains a high percentage of light extremes, however, the use of automated exposure systems can be problematic. TTL controls may respond incorrectly and attempt to modify the exposure so that light or dark areas of the photograph appear to be a medium tone instead.⁶

If a camera analyzes the brightness values of a scene containing a high percentage of white or light areas (e.g., teeth), the TTL light measurement will incorrectly determine there is too much light in comparison to expected midtone values. In this case, the automated exposure would be inappropriately lowered,

and the resultant image might appear artificially dim. If the camera evaluates a composition containing a dominance of dark areas (e.g., the shadows of the pharynx or buccal corridors), TTL light analysis will inadvertently sense there is too little light in comparison to expected medium light values. In this circumstance, the automated exposure would be inappropriately brightened, and the resultant image might appear artificially light.⁶

If a camera analyzes the brightness values of a contrasted scene containing a high percentage of both light and dark areas (e.g., an intraoral scene), the TTL light measurement can vary widely depending on the percentage of light or dark tones included. Even slight alterations in alignment and composition can cause noticeable exposure inconsistency. In this case, the automated exposure could be inappropriately lowered for one image and then inappropriately raised for another of the same subject. The resulting disparity in dim and the bright images can seem haphazard, inefficient, and frustrating for the clinician.

Manual exposure strategies provide the most accurate approach because they are not influenced by the varying amount of light that reflects off light or dark subjects² (FIGURE 5). Instead, an incident light meter is used to determine the amount of light falling on the subject² (FIGURE 6). The clinician selects a desired magnification distance and utilizes the light meter

to determine the proper exposure for that specific distance. When the camera aperture is set manually, the exposure will always be correct for that distance, regardless of the reflective properties of the subject. All subsequent photography at that same working distance can be accomplished with a point-and-shoot style that requires no additional calculation for proper exposure.⁶

Color Accuracy

The colors that are ultimately visualized in a photograph are determined by a combination of the optical properties of the subject, the spectral content of the light illumination, the color processing algorithms in the digital camera, and the workflow of the computer hardware and software used to process the image.⁸ To recreate an accurate representation of the appearance of the optical properties of the subject, the latter three factors must be carefully controlled.

To provide a light source with neutral spectral content, the clinician should select a strobe designed specifically for macro photography. Most contemporary macro flash systems simulate neutral daylight content with a color temperature that approximates 5500 degrees Kelvin (D55)⁸ (FIGURE 7). Other light sources might possess different color temperature characteristics and could impart an inaccurate color cast or tinted appearance to the entire image.

When a photograph is taken, the DSLR camera converts the light energy striking to sensor into digital data that can be stored as a digital file. The white balance feature of the camera influences the computations that are made by the camera during this conversion. The white balance setting must match the color temperature of the light il-



FIGURE 7. Nikon RIC1 strobe system (with a SU-800 radio controller and two SB-R200 slaves) is one of several available strobe systems that have been shown to produce a color temperature approximating 5500 degrees Kelvin when tested at a magnification ratio of 1:2.5.

luminating the photographed scene to properly compensate for its spectral content and eliminate any potential color cast. The photographer can elect to allow the camera to measure light entering the camera to determine the white balance setting automatically or to perform that setting manually.

Contemporary camera systems provide a TTL option for automatically controlling white balance. An internal light monitoring system measures the spectral content of the light entering through the lens to adjust the white balance color processing. Auto white balance algorithms are programmed with the assumption the scene contains a combination of colors that is, on average, neutral. These automated strategies work well when the scene has a balanced variety of red, green, and blue colors, or a predominance of neutral whites, grays, and blacks. Any imbalance in the captured color data would then indicate an unwanted color cast caused by the color temperature of the illuminating light source. The camera's auto white balance processing would alter the data appropriately to achieve a neutral balance and thus improve the color accuracy of the final image.

As with exposure determination, however, the use of an automatic white balance option in photographing an intraoral scene is problematic. Unfortunately, there is no neutral white, gray,



FIGURE 8. The Canon 30D is one of several DSLR cameras that has an external button allowing convenient access for manually selecting the camera's white balance (in this case set to flash, see green arrows).

or black to reference for calibration. There is no green grass or blue sky to balance reddish hues of gingiva and yellow-tinted hues of teeth. Auto white balance processing will erroneously add cyan to the image to neutralize the high proportion of red from the gingival tones while adding a tinge of blue to offset the yellow tones of the teeth. The resultant image will predictably seem to have an inappropriate bluish-gray cast.

To control the color processing algorithms of a camera for the most accurate color results, the photographer must set the white balance feature manually to match the light source and to coordinate with its specific color temperature.^{3,5} The camera would then be compensating for the quality of light falling on the subject rather than the limited portion of the visible of the spectrum reflecting off the subject. Although a custom white balance profile can be produced to provide the best camera response, the flash white balance setting is a good starting point for clinicians who are taking initial steps toward improving color accuracy in their photographs.

The camera processes the captured color data of the digital image with the assumption that the spectral content of the light illuminating the subject closely approximates D55.^{5,8} Major camera manufacturers often use a lightning bolt icon to symbolize flash features and to indicate when they have been selected (FIGURE 8).



FIGURE 9. Pretreatment evaluation image taken with manual exposure settings dictated by an incident handheld light meter.

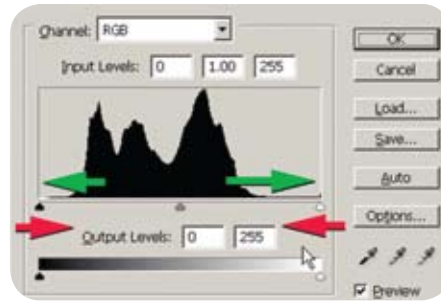


FIGURE 10. The histogram of the tonal content of the image shown in Figure 9. The slider controls of this software tool can be moved (see red arrows) to expand the tonal content and alter the appearance of the image (see green arrows).



FIGURE 11. The same pretreatment evaluation image seen in Figure 9 but with an expanded tonal content. The image displays significantly increased contrast but also altered color content.

Software Workflow

Computer hardware and software must be utilized to view digital images after they are captured. Whether or not a clinician learns to perform these procedures or elects to outsource or delegate the completion of the tasks to others, some form of digital processing must occur to convert the initial image data into a monitor screen display or a print. The selection of equipment, use of software, and application of image processing all affect the quality and accuracy of the final photographic result. Knowledge regarding the nuances of image processing is necessary to obtain proper results.³

The workflow is the series of steps, either automated or manual, that is applied to digital images as they are processed for viewing. One critical workflow component is that of database management. Sorting, selecting, naming, and storing images are essential procedures that allow efficient retrieval of images for later viewing.³

Beyond organizational tasks, computer software provides the photographer with ability to alter the size, format, or content of the images. The possibility of modifying a medicolegal record of diagnosis and treatment raises an ethical question. If an isolated selection of only part of the pixels within an image is altered by itself, the appearance of that portion will change relative to the remainder of the picture. This capability enables the operator to create images

that simulate proposed treatment results and help patients visualize the possible esthetic benefits of dental care. Unfortunately, it also creates a potential for the operator to falsify the appearance of the image, hiding unwanted elements that are present or creating the illusion of other elements that are missing.

Clearly, the practice of furtive or fraudulent image alteration has no place in dental practice and the issue warrants extensive discussion in another forum. The focus of the remainder of this article will be on the wisdom of attempting to correct images in the ethical intent of accuracy rather than that of deceit.

Global image changes are software manipulations that are performed over all the pixels in the entire image.³ Image rotation is one example. If a clinician mistakenly holds the camera in a tilted aspect relative to the patient's dentition during capture and inadvertently creates a canted dental image, rotation can be applied correct the error and provide improved representational accuracy.

Unfortunately, an angled portion of each corner of the image must be trimmed away and eliminated to maintain the original shape and aspect ratio. Even though the impact of improved alignment may seem to provide an enhancement, the software alteration has reduced the data contained in the image, altered its apparent magnification, and therefore reduced its diagnostic accuracy.

Similar software strategies can be applied to alter the luminosity of an image by globally modifying the brightness levels of its pixels. Evaluation of the efficacy and advisability of this workflow procedure requires the analysis of a histogram. A histogram is a bar graph that represents the tonal content of an image (**FIGURES 9 AND 10**). The x-axis designates the brightness levels of the tonal range, with pure black at the far left and pure white at the far right. Dark tones in the left third of the histogram are called the shadows of the image. Light tones indicated by the right third of the graph are called the highlights. The medium tones represented in the middle third of the histogram specify the midtones. Each column of the bar graph represents a unique and discernable color brightness from its adjacent neighbors. The more tonal levels present in an image, the greater the quality of detail it can contain. The y-axis of the graph corresponds to the percentage of pixels within the image at each tonal level. A higher peak of the graphed data represents a greater proportion of pixels with that specific luminosity present within the image.

When software is used to change the tonal content of a photograph, a corresponding change will be seen in the histogram as well. By moving the sliders under the histogram, the software repositions the white point and black

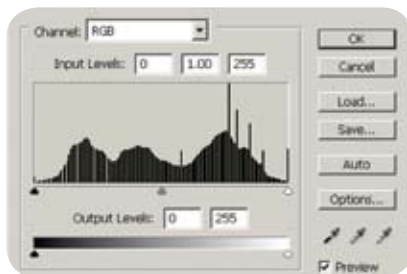


FIGURE 12. The histogram of the altered image in Figure 11. The widened graph of data (in comparison to Figure 10) reflects an expansion of tonal range. Although promoted as an image correction, there are now gaps in the data, loss of detail discernment, and image degradation.



FIGURE 15. The same ideally exposed image as in Figure 3 seen as originally published without alteration and modification during publication. Note the neutral and expected appearance of the gingiva.

point, proportionally redistributes the tonal values for all the pixels in between, and mathematically reassigns their red, green, and blue values to match.

Often this technique is utilized to enhance tonal contrast by making dark tones appear darker and by making light tones appear lighter (FIGURES 10 AND 11). Histogram-assisted brightness level manipulation has also been proposed as a method to compensate for initial exposure inaccuracies. This workflow application implies that exposure errors inherent in automatic TTL exposure don't matter because they can be corrected.

Myths of Image Alteration

Brightness level changes are simply mathematical alterations of the red, green, and blue numerical formulae that correspond to each pixel. Lower values correspond to darker shadows



FIGURE 13. The same overexposed image as in Figure 1 seen as originally published following inadvertent alteration and modification during publication. Note the orange cast in the appearance of the gingiva.



FIGURE 14. The same underexposed image as in Figure 2 seen as originally published following inadvertent alteration and modification during publication. Note the purple cast in the appearance of the gingiva.

while higher values represent brighter highlights. Squeezing the white and black points toward the center of a histogram, however, also forces the pixel data to be distributed over fewer tonal levels. Often pixels that were previously defined by differing RGB formulae are now combined and lumped together as being the same. The consequence of identical pixel appearance is always a loss of image detail.

In addition to the irreversible reduction in image detail, the combined tonal levels are stretched out to cover the entire tonal range. Darker brightness levels must shift toward the black at the far left while lighter brightness levels must approach white at the far right. Histogram evaluation following tonal level manipulation reveals the exaggerated spikes of collapsed tonal level detail separated by gaps of missing data left behind as a sequella of that process. Gaps in the histogram data graph are manifested as a patchwork quilt appearance detracts from the continuous gradient of tones that should be present in an excellent photographic representation of skin, gingiva, and teeth. Regardless of the effect of increased contrast or the illusion of exposure correction, any alteration of the brightness levels of an image will always degrade the detail of the image (FIGURE 12).

Since brightness level manipulations are produced by RGB formula changes

for every pixel, any alteration in the tonal range will also alter the perceived color content in the final image. In another article by this author, three images were submitted to demonstrate the need for exposure accuracy⁷ (FIGURES 1-3). Those images were intended to illustrate how overexposure can ruin detail discernment in the highlights while underexposure obscures detail discernment in the shadows.

During the publication process, the graphics department noted the disparity in the appearance of the three images and decided that the intentional difference was actually an unwanted mistake. The tonal content of the images was globally altered by the publisher so that the teeth in all three photographs would appear to look more uniform⁷ (FIGURES 13-15). Although well-intentioned, this error dramatically illustrates how the alteration of tonal content simultaneously and undesirably alters color content. The images were all captured utilizing the same patient, but the appearance of the color content of the gingiva is significantly different.

Images can be adjusted with objective computer-analyzed protocol for improved color accuracy. With subjective histogram referencing techniques, however, color results can easily be skewed and inaccurate. Manual exposure techniques, manual white balance settings, and minimal software manipulation will yield the most pre-

dictable photographic results. For the best images, there is no substitute for accuracy and excellence in photographic technique.⁷

Conclusion

Digital photography can aid in diagnosis, treatment planning, delivery of care, and medicolegal documentation. Exposure accuracy is an essential factor for capturing and viewing correct representative images of clinical conditions. Manual exposure and manual white balance selection yield the most efficient, predictable, and consistent photographic results. Clinicians will achieve the best

results through the implementation of good photographic techniques rather than subsequent image manipulation with computer software. ■■■■

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CONTACT Stephen R. Snow, DDS, Snow Dental Care, 909 San Ramon Valley Blvd., Suite 216, Danville, Calif., 94526.