DIGITAL DOCUMENTATION AND THE DENTAL OPERATING MICROSCOPE: WHAT YOU SEE IS WHAT YOU GET

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The importance of regular digital photography and documentation in the dental office cannot be understated. The many uses for documentation include publication, diagnosis and treatment planning, dentolegal documentation, forensic documentation, insurance verification, patient education, marketing, and communication with laboratories, dental team members, and colleagues. With the introduction of the dental operating microscope into dental treatment, the ease and scope of documentation have been drastically improved. Images and video taken with the microscope can show details that would not be visible with conventional photography. The aim of this article is to provide an overview of the equipment and techniques available to achieve high-quality digital documentation using an operating microscope. *Int J Microdent* 2009;1:30–41

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In the late 1980s, Dr Gary Carr, who is considered the pioneer of microscopic endodontics, was working with Dr Terry Tanaka in a research lab in San Diego. Dr Carr was doing dissections of temporomandibular joints of cadavers under an operating microscope. Dr Carr pondered how the tremendous visual acuity offered by the microscope might revolutionize the discipline of endodontics. He then set about improving the original dental microscope developed by Dr Harvey Apotheker in 1981, so that it could be used for both surgical and nonsurgical root canal therapy. Dr Carr realized that in order for the field of endodontics to accept such a drastic departure from low magnification "tactile-driven" endodontics to the inclusion of a microscope and "vision-based" endodontics, capturing his view through the microscope for others to witness was essential. Quality photography through the microscope was needed to show others how refined apical surgery could be performed with this new technology. Early documentation using the dental operating microscope involved 35-mm cameras with strobe flashes for photography (slides and prints) and analog one-chip video cameras mounted on the microscope and connected to a video cassette recorder for acquiring video. The change to digital imaging from analog sources was time consuming and often resulted in loss of detail. In addition, the clinician had trays full of slides and videotape strewn around the office, without an organized system of cataloging or storing the images. The development and improvement of digital point-and-shoot and single-lens reflex (SLR) cameras as well as digital video cameras over the past 10 years has simplified the microscopic documentation of dental procedures. The relative ease of capturing both still images and video, as well as the increased availability of image editing and archiving programs, has significantly shortened both the learning curve and the time involved in capturing multimedia data during dental procedures (Figs 1 to 3).

Fig 1 The author and his assistant at work in the microscope-centered operatory.

Fig 2 Original Global Protege Plus 6 microscope with strobe flash, Contax 35-mm slide camera on the right side, and one-chip analog video camera on the left side.

Fig 3 Microscope with Nikon Digital SLR camera on the right side, a Nikon SB-29 ring flash mounted at the bottom, and a Sony three-chip digital medical-grade cube camera on the left side.

REASONS FOR DOCUMENTATION

Many authors have cited reasons for the importance of regular digital photography in the dental office, including: diagnosis and treatment planning, dentolegal documentation, forensic documentation, insurance verification, patient education, marketing, and communication with laboratories, dental team members, and colleagues.[1,2] A number of authors[3–8] have discussed the improved ease of documentation with the dental operating microscope. The medical field has seen the value of digitally driven documentation for neurology and other disciplines.[9–11] There are many reasons why the microscope offers significant advantages over traditional documentation for dentistry. Traditional SLR cameras are limited to a nonoptical magnification of around 4× to 6×, whereas most microscopes have a magnification range that is between 2× to 20×. At the lower ends, the microscope can easily capture a smile from commissure to commissure (Figs 4 to 6).

With a simple change of the magnification turret and a quick release of the shutter, higher magnifications such as 20× can be photographed. Higher magnifications above 10× power are extremely visually effective and informative. These images show details such as cracks, open margins on restorations, incipient decay, or minute irregularities in the preparation or restoration of the tooth that are not visible with conventional photography without digitally zooming in from a high-resolution photograph. When digitally zooming, a pixilation or fuzziness can appear unless the resolution of the original image is very high. In addition, digitally zooming in loses the value of capturing what is seen intraoperatively through the microscope. This leads to instances where the camera captures details that were not observed during treatment that can minimize the educational power of the photographs. This issue cannot occur with microscope photography because what the operator sees through the oculars intraorally while working is captured digitally by the camera. What you see is what you get. Reduced time is a significant benefit of integrating the microscope for digitally photographing dental procedures. Typically, when case documentation is desired, clinicians will often schedule the procedure on a day that is free of other appointments to allow for the increased time needed to capture the various steps. Operators need to continually suspend the procedure, de-glove, set up the camera, and photograph the case at the same angle and magnification to assure standardization.

Fig 4 Photograph taken on the Global G6 demonstrates a nonretracted smile from commissure to commissure (magnification ×2.1).

Fig 5 Photograph of the retracted smile (magnification ×2.1).

Fig 6 The gingival tissue and cementoenamel junction of the left central incisor of the same patient (magnification ×13.2).

With the operating microscope, however, the simplicity of capturing images or video while working through a remote or manual release of a shutter allows the clinician to document every procedure instead of only certain cases. Often during a routine dental procedure, cracks, cuspal fractures, pulp exposures, decay on adjacent teeth, missed canals in endodontics, and various other issues crop up (Figs 7 to 12). These unanticipated events are far easier to discuss with patients when they have been documented throughout the procedure. In his landmark research, Mehrabian[12] found that over half of all comprehension during communication comes from nonverbal cues. After all, patients remember 10% of what they hear and 50% of what they see, giving rise to the famous saying, "A picture is worth a thousand words." Considering this, how much is a magnified real-time image or video worth? Many clinicians are searching for more effective methods with which to develop lecture and educational materials. The standard before-and-after photographs, so often a staple of cosmetic dentistry presentations, do little to inform the attendee of how the results were achieved. Real-time video, when connected to an operating microscope, has been shown to improve treatment outcomes and the teaching process.[13] Obtaining images from digital video cameras positioned externally for procedures in the maxillary or mandibular anterior regions is relatively simple. It is more difficult to capture video images that are magnified or taken in the posterior segment of the oral environment. The microscope offers the practitioner the opportunity to attach a consumer-grade video camera to the microscope (Fig 13). The digital video can then be edited via a computer in simple editing programs such as iMovie (Apple) or Windows Movie Maker (Microsoft) and subsequently used in lectures and educational materials. The author routinely uses photographs and videos of procedures for use in a wide variety of situations to educate patients, colleagues, lab technicians, and staff.

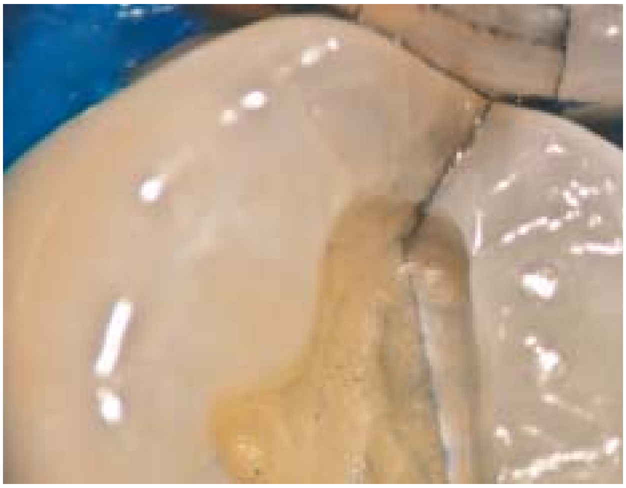
Fig 7 Horizontal fracture of the lingual cusp (methylene blue; magnification ×13.2).


Fig 8 First and second mesiobuccal canals on a maxillary molar (magnification ×13.2).


Fig 9 Tissue around the crown margin of the maxillary central incisor (magnification ×13.2).


Fig 10 Occlusal decay of a mandibular molar (magnification ×13.2).


Fig 11 Use of a diode laser to treat pulp exposure (magnification ×13.2).


Fig 12 Removal of clear translucent resin luting cement from a porcelain laminate veneer (magnification ×13.2).

Fig 13 Sony high-definition video camera mounted to a Global G6 microscope.

Fig 14 Components for the Global G6 microscope, including a dual-port beamsplitter, camera adapter (Xmount), and point-and-shoot digital still camera.
(Photograph courtesy of Global Surgical Corporation.)

EQUIPMENT

The microscope itself requires the addition of three pieces for it to be adapted for documentation regardless of whether the final camera is a video camera or an SLR camera. These three basic components are the beamsplitter, camera adapter, and camera (Fig 14). There are also supplemental components that can make the documentation easier, including monitors, light sources, dual iris diaphragms, and specially coated mirrors. Finally, a computer and computer software will be needed for editing and storage.

Basic Components

Beamsplitter. The beamsplitter is an accessory that fits into the microscope body, and its function is to split the light beam through two cube prisms so that a portion of the light goes to the camera system and the remainder continues on to your eye. The light is reflected and transmitted through partially reflective coatings on the prisms, which cause the light beam to follow one of the two pathways (Fig 15). Beamsplitters come in a variety of configurations, such as the traditional 50/50 variety just described. Some simple digital cameras and most video cameras can work with less light coming across the digital sensors, so varieties such as 80/20 or 95/5 virtual beamsplitters allow more of the light to go to the eye. This means that the image will appear brighter since less light is lost to the camera. Unfortunately, many of the cameras today are higher resolution cameras that have more pixels. This requires that a greater amount of light needs to fall over the charge-coupled device or complementary metal oxide semiconductor sensor where there are now more pixels, each of which is smaller in size. In microscope photography, lighting is the biggest obstacle to getting great photographs. You can never have too much light. If the amount of light is inadequate, this will result in dark, grainy, or blurry photographs, particularly at higher magnifications. Even today's consumer-grade video cameras have sensors that have more pixels and require more light. The only exception to this is a medical- or surgical-grade video cube camera where smaller amounts of light are required for the camera to be functional. Otherwise, the best suggestion is to go with a 50/50 beamsplitter. Beamsplitters come in one-port and two-port varieties. The one-port beamsplitter has only a single side or port, so only one camera can be added. Dual-port beamsplitters have a right and left side for adding two camera systems to the microscope. Each microscope manufacturer makes a variety of beamsplitter configurations. Zeiss even has a beamsplitter and ergonomic adapter built into one unit for their Pico microscopes (MORA adapter).

Adapters. The adapter is a cylinder with lenses inside that carry the light to the camera so that it focuses right on the sensor and fills it to the maximum level. These adapters connect

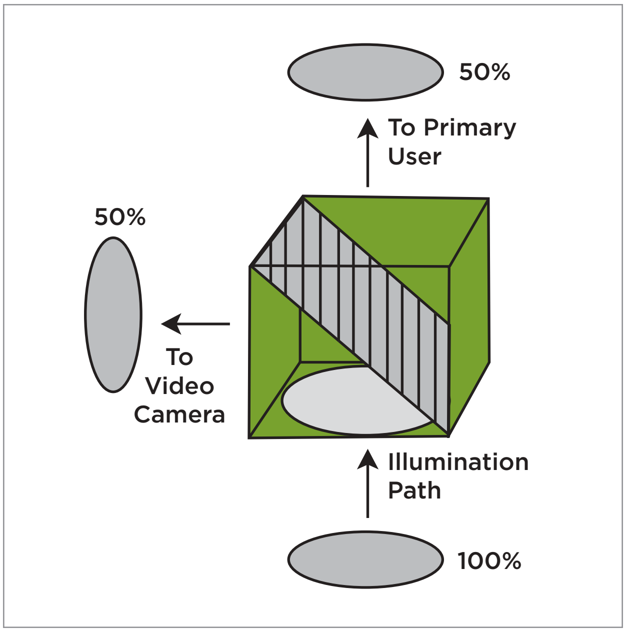

Fig 15 Light reflectance inside a 50/50 beamsplitter. *(Photograph courtesy of Global Surgical Corporation.)*

Fig 16 *(right)* Zeiss Flexiostill adapter for point-and-shoot digital cameras. *(Photograph courtesy of Zeiss.)*

Figs 17a and 17b Zeiss Flexiomotion adapter for consumer-grade video cameras. *(Photograph courtesy of Zeiss.)*

the beamsplitter to the camera and have varying focal lengths depending on the type of camera and the brand. Since the lenses and sensors are different in various brands and types of cameras, the adapters are designed to work best with both the type of microscope and camera chosen. For instance, Zeiss uses the Flexiostill adapters to attach a point-and-shoot digital camera, while Global uses the Xmount adapter. In contrast, to attach a consumer-grade video camera to a Zeiss microscope requires the Flexiomotion adapter. Global offers the Xmount SLR adapter to connect SLR cameras to its microscopes (Figs 16 and 17). There are also third party companies that make adapters for cameras that may be less expensive and will fit other scopes such as Kaps, Seiler, Leica, etc. These include: GBC innovations, TTI Medical, and Endure Medical.

Cameras. Over the last 10 years, digital camera systems have started to replace 35-mm film-based systems, meaning that film is becoming obsolete. The same transformation that has occurred in the field of photography has happened in the field of microscope documentation. Initially, the cameras that were developed were simple point-and-shoot cameras such as the Nikon Coolpix series, which were lightweight and simple to set up on the microscope (Fig 18). The image is composed, framed, and focused from the LCD monitor on the back of the camera and not through the viewfinder. These cameras also had the option to connect to a monitor via a video-out cable, which allowed for a live video stream to be shown. These cameras were replaced by SLR cameras, which work more like traditional photographic cameras. They have the ability to swap out a variety of lenses and typically have sensors with more pixels. The images are captured through a viewfinder. Recent versions like the Canon EOS Rebel T1i and Nikon D90 and D5000 can capture short movie clips as well as digital stills to the memory cards, which have replaced film as the storage medium. Finally, consumer-grade video cameras can be attached to the microscope and now provide high-definition video in a lightweight package. These high-definition video cameras are compact, work very well in low-light situations, and provide better depth of field than a still camera. Although these cameras now provide digital stills that are up to 10 to 12 megapixels (interpolated), the color rendition and sharpness of these images are not comparable to those obtained with a dedicated high-end SLR camera (Fig 19). The last few years has seen a convergence of technologies in which digital still cameras are beginning to be able to take quality videos and high-definition video cameras are able to take decent stills captured to a hard drive or memory stick, or even captured as a single frame from the video itself (see Figs 2 and 13).

I prefer to have a dual-port beamsplitter with a dedicated port on the left side (my nondominant eye) for a medical- or surgical-grade cube cam-

Fig 18 Nikon 5000 point-and-shoot camera on the left side of a Global G6 microscope.

Fig 19 Canon SLR camera on the left side of a Zeiss ProErgo microscope and a medical-grade cube camera on the right side. *(Photograph courtesy of Dr Wade Karhan, Rittman, Ohio.)*

era, which allows for video to be sent at all times to monitors throughout the microscope-centered operatory. On the right side (my dominant eye), I prefer to have an SLR Nikon camera (Nikon D90, D5000, or D300) with a ring flash attached to the bottom of the scope, which provides more light for photographs at higher magnifications. Canon also has a large selection of SLR cameras that easily attach to the microscope. The importance of ocular dominance (ie, the dominant eye) of a person cannot be overlooked. Ocular dominance is the tendency to prefer visual input from one eye to the other. Although it is somewhat similar in concept to right- or left-handedness, the side of the dominant eye and the dominant hand do not always match. Approximately 66% of the population is right-eye dominant; therefore, the right eye is primarily relied on for precise positional information. For microscope users, this means that the parallax stereoscopic vision that occurs while looking through the microscope is primarily dependent on only one eye. For right-eye dominant people, what they see when both eyes are open is the same as when only the right eye is open. There are numerous tests available for testing ocular dominance, but perhaps the easiest is the Porta test. The observer extends one arm, then with both eyes open aligns the thumb or index finger with a distant object. The observer then alternates closing the eyes or slowly draws the thumb/finger back to the head to determine which eye is viewing the object (ie, the dominant eye). When the dominant eye closes the image will shift to one side.[14] The primary camera system used for the microscope should be located on the side of the beamsplitter that matches the dominant eye of the clinician.

Supplemental Components

Monitors. One of the best things that a serious microscope photographer can do is to hook up an LCD monitor to the microscope camera either through regular S-video or composite (yellow input) video cables. Newer monitors have multiple inputs, including computer inputs (DVI and VGA) and the now common digital HDMI outputs that most cameras and video cameras use to transfer both audio and digital signals. Since at higher magnifications the depth of field is only millimeters in size, it is important to gain instant feedback as to the exposure, framing, and focus of the image. The clinician must set up the scope oculars to be in synchronization with the camera (ie, parfocalling) in order for the final image to be an exact replica of what is seen through the oculars. With point-and-shoot cameras and video cameras, the monitors serve to compose the images prior to actual shutter release. It is far easier to see on a large 19- to 40-inch monitor whether the object in the operating field is located centrally in the screen (framing), and a reticle crosshair or circle in the dominant eyepiece can make this easier as well. Once the shutter is released, the monitor shows instantly whether the image is in focus and properly exposed. Analysis of the histogram is essential to determine if the image is underexposed (too dark) or overexposed (too bright). When the image is properly

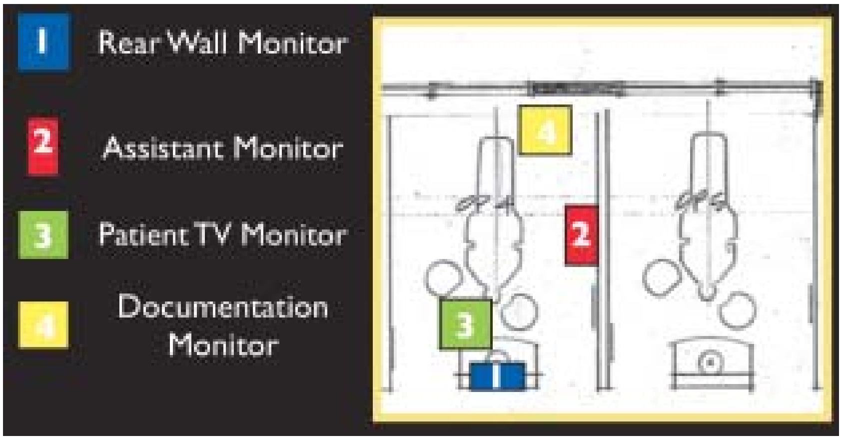

Fig 20 Suggested positions of the four monitors in a microscope-centered operatory.

Fig 21 *(Right)* Forty-inch LCD monitor mounted at the foot of the chair to allow the clinician to properly and immediately assess framing play back, focus, and exposure of the images. In addition, the monitor can be used to play back images from the camera after the procedure for patient education.

exposed, there should be a bell curve of exposure centered or slightly to the left in the histogram. Even with the larger 3-inch LCD screens on newer cameras it is next to impossible to determine if images are properly acquired. I have four monitors hooked up in my operatory (Fig 20). I have a 40-inch LCD Sony Bravia monitor located at the foot of the operatory that displays the images as they are captured and is also used for patient education by putting the camera into playback at the end of the appointment to demonstrate the procedures (Fig 21). In addition, a 22-inch monitor that is directly across from the dental assistant and connected to the surgical-grade cube camera allows the assistant to view the procedure from a microscopic standpoint while still being able to see the macroscopic world when needed. An alternative that is more commonplace in the endodontic discipline is to have an assistant's side to the microscope that will provide the assistant a much-improved three-dimensional view of the surgical site compared to the two-dimensional monitor. Finally, the patient has an overhead 22-inch monitor that displays either television or the live procedure (again from the medical-grade cube camera) depending on the patient's desire. An Apple 20-inch IMac at the rear of the operatory completes the monitor setup. Monitor prices have dropped so much over the years that they are now essential items to augment the basic photography items listed above.

Light sources. As mentioned previously, the amount of light is the key to obtaining sharp, properly exposed images with great depth of field. In fact, you can never have enough light for the cameras, particularly at higher magnifications. To increase the amount of light, the operator can alter several camera options. The ISO setting can increase the sensitivity of the sensor, but this creates a grainier or noisy image. Shutter speed can be reduced, but this increases the risk of a blurry or poorly focused image. The aperture can also be adjusted, but because most SLR cameras do not need a lens to connect to the adapter, the ability to control aperture on the microscope falls to the dual iris adapter. The clinician can also use items other than the camera itself to provide more light, including a brighter light source such as a xenon bulb, which will provide more light than a standard halogen bulb. Some companies are now making metal halide bulbs, which provide a happy medium of intensity of light and are much less expensive than xenon bulbs. I have found that by adding a ring flash to the body of the microscope (see Fig 2), the microscope is able to take photos at a much lower ISO, at faster shutter speeds, and with a greater depth of field. In fact, in many instances the amount of light that is provided is in excess of what the camera requires and can be lessened by adding an aperture (dual iris diaphragm) to the microscope. By adding the aperture to the body of the scope, the clinician will find a far greater effect on the shallow depth of field inherent in the microscope than if the aperture is placed on either the adapter or the camera itself (Figs 22 and 23). In addition, specially coated mirrors

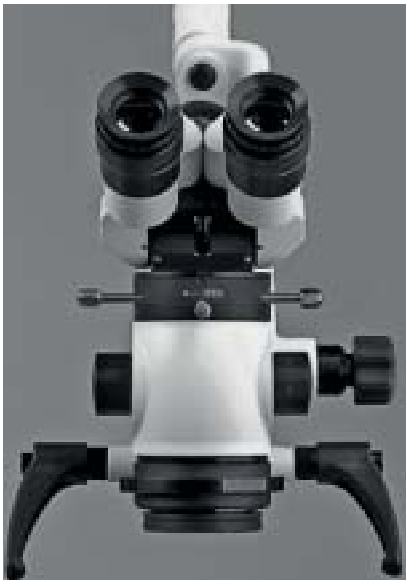

Fig 22 *(left)* Dual iris adapter situated between the magnification turret and oculars.

Figs 23a and 23b Dual iris diaphragm open *(center)* and closed *(right)*. *(Photograph courtesy of Global Surgical.)*

Figs 24a and 24b Images taken using specially coated mirrors *(left)* are much brighter than those taken with standard dental mirrors *(right)*. *(Photograph courtesy of Global Surgical.)*

such as those available from Zirc or GBC Innovations will reflect more of the available light to the camera and improve the quality of the photos over less reflective standard dental mirrors (Fig 24).

DOWNLOADING IMAGES

Once images have been properly captured, they must be transferred to the computer for archiving and/or editing. The images can be transferred by removing the memory card and loading it into a card reader or by USB2 connection from the camera to the computer. Wireless transmission of images is also feasible using either a wireless transmitter specific to the SLR camera or a wireless camera card if the camera uses compact flash or SD memory cards. Eye-Fi software (Eye-Fi) is a simple and inexpensive solution that allows for images to be uploaded to computers or file sharing sites, provided that a wireless router is available in the office. Canon cameras come with a software package called either Breeze or Remote Capture, both of which allow for images to be transferred via a USB2 cord directly from the camera to the computer. The computer itself can even trigger the shutter release, avoiding the blurred images from camera shake that can occur while manually triggering the shutter. Nikon provides similar software for its cameras. At present, it is not feasible to wirelessly transfer video directly into a computer, but this may soon change as wireless transfer rates increase. For now, the use of either USB2 or firewire cables allow for video to be transferred directly into the computer. Medical-grade one-chip and three-chip video cameras, which are analog in nature, can be connected directly to a video capture card in the computer that will digitize the analog signal. Be aware that doing this will significantly alter the resolution of the image when compared to the high-definition digital video systems, but the file size for these digitized videos is significantly reduced. Consideration must be given to the file size of both video and still images, because the larger the resolution, the larger the

Fig 25 View of the editing program (Adobe Lightroom 2) used by the author.

Fig 26 iMovie video editing software.

file size. Larger files will have slower transfer speeds and will more quickly fill up the hard drive. Therefore, whether the videos and images will be used for publishing or for simple patient education and dentolegal applications should be considered when planning the size and quality of the files used. The higher the resolution of the files, the faster the computer will need to be.

SOFTWARE

Image Editing

The standard image-editing program for professionals is Adobe Photoshop, but this program is both expensive and difficult to master. Many basic programs exist that range in cost from nothing at all to several hundred dollars. Middle of the range programs such as Aperture (Apple), Adobe Photoshop Lightroom, or Adobe Photoshop Elements (a stripped-down version of Photoshop) offer elegant editing solutions to give images that "pop" for lecturing or publishing purposes (Fig 25). Many clinicians insist that editing be limited to cropping or straightening; however, simple tasks such as improving contrast, brightness, clarity, and sharpness can enhance image detail without misrepresenting the original image and treatment outcome.

Archiving

Programs such as ACDSee (ACD Systems) and Thumbs Plus (Cerious Software) allow users to categorize their images. Fortunately, most dental practice management software programs already have imaging components that allow storage and basic editing of the captured images. Software programs such as TDO (for endodontics) are fantastic for capturing, storing, and even tagging the photographs not only to the patient's chart, but also so that comparison of similar cases can be easily and quickly done. These programs allow for storage of radiographs as well. With respect to video cameras, many editing programs are available for creating short movies. These

TABLE 1 How to control settings for high-definition consumer-grade video cameras for microscope photography

Setting	Alteration
White balance (controls "temperature" of color)	Use "one push" on Sony Handicams for custom white balance; press once with a Kodak 18% gray card (available at photography stores) or a white sheet of paper under the scope
Focus (allows camera to focus on object through the microscope)	Set to "Manual" focus for most video cameras (depending on adapter and camera) and adjust the focus to "Infinity" or "Mountain" (this prevents accidental automatic focus of the video camera on objects such as handpieces, mirror surfaces, etc)
Autoexposure (AE) shift (controls brightness of image)	Set to +1 or +2 to increase brightness, particularly at high magnification and depending on light source used

TABLE 2 How to control settings for Nikon digital SLR cameras with ring flash for microscope photography

Setting	Alteration
White balance (controls "temperature" of color)	Set to "Flash" with ring flash; use "Preset" without ring flash
ISO (controls sensitivity of the sensor to light)	Set to 200–320 with ring flash; use "Auto ISO" without ring flash
Shutter speed (controls exposure time, ie, how long light is allowed to reach sensor)	A minimum of 1/125 per second reduces blurriness from camera shake; remotes are also helpful
Quality	Set to "Fine" (use "RAW" when editing white balance)
Size	Depends on use (eg, larger files for publication, smaller for patient education)
Metering (controls how camera reads the light to calculate exposure)	Set to "Matrix" or "Spot Metering"

range from introductory programs such as iMovie (Fig 26) and Windows Movie Maker to advanced systems such as Final Cut Express (Apple) and Adobe Premiere. The choice of software package depends on the computer skills of the clinician, budget, and reasons for use.

CAMERA SYSTEMS AND SETTINGS

Several factors come into play when attempting to take excellent photographs from the microscope. The settings are only as good as the operator. The clinician must spend time learning how to position the microscope at higher magnifications, because it is only above 5× magnification that images from the microscope exceed those achievable with standard digital cameras. The clinician must understand the basic settings of his or her system (Tables 1 and 2) as well as the basics of image editing. Many clinicians simply wish to capture a few images and not worry about editing, and that too is fine as long as suboptimal photographs are acceptable. Currently, the two most common systems revolve around high-definition consumer handheld video cameras to produce excellent video and decent stills. Such systems (see Fig 13) appeal to those looking for simplicity at a reasonable expense while optimizing the ability of the video cameras to work in reduced light with a higher depth of field. These cameras do not work as well for still photographs (color rendition and sharpness) as a dedicated SLR camera with a flash system, but are ideal for many endodontists looking for a lightweight system to attach to the microscope. Although smaller and lighter-weight surgical-grade high-definition video cameras are available from several manufacturers that can take decent still images, their cost as of now is still significant when compared to the larger consumer-grade video cameras. For a restorative dentist who is experienced with SLR photography in dentistry and wants truer colors in the red range and the ability to capture small video clips, an SLR camera (Nikon D90 or D5000, Canon EOS Rebel T1i, or the more expensive Canon 5D Mark II) with a ring flash will provide optimum still photographs (see Fig 2). These systems are not as simple to operate as the video cameras, but they offer images that more closely resemble those obtained from dedicated SLR cameras when not mounted on the microscope. As these cameras become more sophisticated with higher ISO settings, the need for a flash may become less of an issue. In addition, as the convergence between video and still photography continues, there will come a time (if it is not already here) when one camera will do both jobs very well.

CONCLUSIONS

The aim of this article was to give microscope enthusiasts some information about the current state of digital documentation using an operating microscope. The world of cameras is a rapidly changing one—most camera cycles last 2 years—so it is important for the clinician to look for a system that is current, since it may soon be replaced by a newer and faster model in this never-ending upswing of technology.

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