Chapter 2

Ophthalmic Imaging Essentials for Telemedicine

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This chapter addresses the following

Key Concepts:

- In the digital realm of ophthalmic imaging, an image is worth a million words.
- The greater the number of pixels – on which digital photographs are usually based – the finer the detail.
- Designating each picture element (pixel) to one of three additive primary colors – red, green, or blue – creates a color digital image.
- In telemedicine applications, large files that contain fine clinical details must be balanced with transmission requirements that favor more compact files.
- There is a strong relationship between the amount and type of image compression and the quality of the information that is transferred.
- Ophthalmic imaging encompasses a wide range of photographic modalities, each of which is designed to capture a specific type of visual information.

2.1 Introduction

Whoever coined the timeless expression, “a picture is worth a thousand words,” must surely have had the application of ophthalmic photography to telemedicine in mind. For while ophthalmic specialists can describe their patients with words and numbers, nothing tells the story of a patient’s ophthalmic health status as well as a fine, digital photograph (Fig. 2.1).

To appreciate the intricacies and contributions of ophthalmic imaging, consider the digital application of the word *retina*. The six letters making up this description are encoded into the computer using six different American Standard Code for Information Interchange (ASCII) characters, each of which is a specific two digit number that is represented in a single byte of memory. This means that the word *retina* uses six bytes of computer space. Therefore, multiplying the word *retina* by one million results in a six megabyte image file – a *picture* that might reasonably be said to describe the word *retina* (Fig. 2.2).

There is also a third meaning to the expression, “a picture says a thousand words,” because an image is the end result of a long, multi-step imaging chain. The subject is first chosen, lit, and precisely framed. Upon the photographer’s decision, the light arriving from the subject enters the camera lens, passes through the open shutter, and strikes the digital sensor. This exposure initiates an electronic signal that is processed digitally within the camera, which, in turn, is transferred to the computer. The digital image’s input into the computer drives a specific series of events that involve storage media, the computer hard drive, random access memory (RAM), the communication bus, and many electrons. The image is processed (digitally, not conventionally) before it is presented on the screen or printed. So the end product – a single image exposed in a fraction of a second – is, in reality, the result of a long, multi-step process.

This chapter provides an introduction to digital ophthalmic imaging for telemedicine. It be-

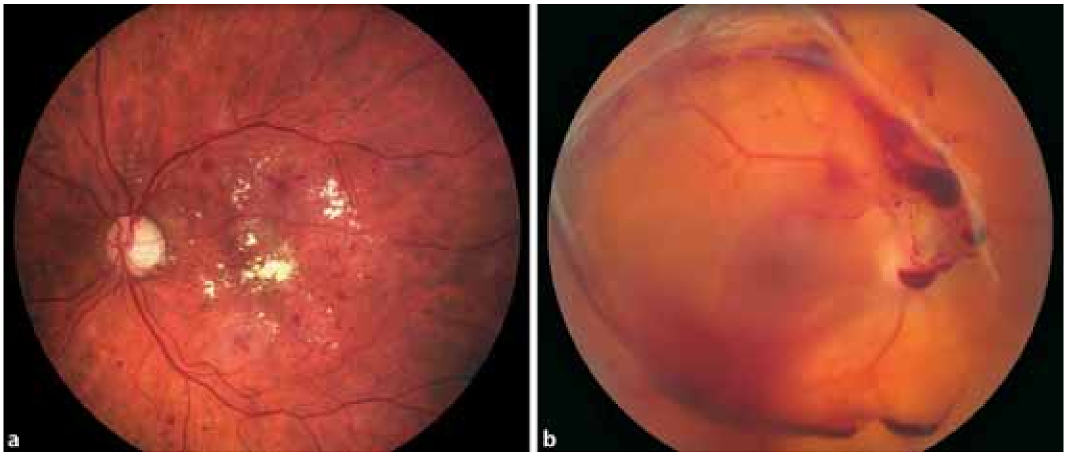

Fig. 2.1. Examples of two patients with similar demographics, similar visual acuity (20/400), and similar history (diabetes for 13 years). Retinal photography highlights the variable outcomes of their common disease process

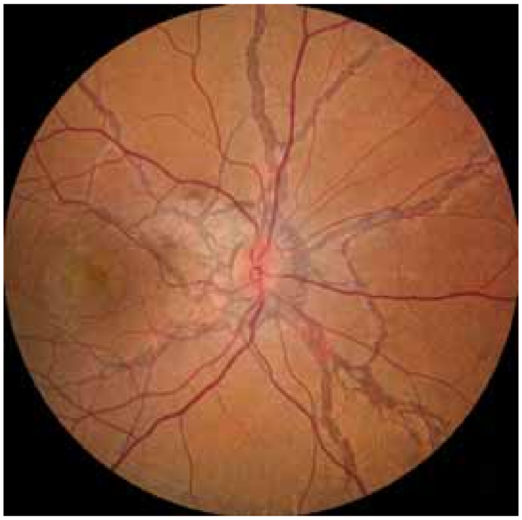

Fig. 2.2. This 24 bit color image of the retina uses 6 megabytes of computer space. The file uses 1 channel each of red, green, and blue information. It was sent to the printer as a 4.8” x 4.8” 300 DPI .tif file.

gins by explaining the essential tenets of digital imaging and concludes with a description of digital imaging instrumentation.

2.2 Digital Imaging Essentials

When a digital image is created, the image does not really exist. This is because, unlike traditional photographs, a digital image is really just an electronic description for creating an image – as opposed to an actual physical object. As descriptions, digital images use specific parameters to recreate an impression of the original object. As in art, digital images are conceptual as opposed to exact physical replications, and they consist of four key components: pixels, color, file formats, and data compression.

2.2.1 Pixels

Computer descriptions come in two basic varieties: vector based and pixel based [1]. Vector based images use mathematical equations to describe the image. These are generally compact (small file sizes), and therefore are not very efficient at conveying large amounts of small detail.

Digital photographs are usually pixel-based images. Each pixel represents a single point in a graphic image – similar to dots in halftones or in grains of film. Both the physical size of the pixels and their density on the imaging chip can affect their ability to resolve fine detail. In the simplest of examples, these pixels can be turned on or off, in which case they can be distributed to create a black and white image. Of course, the greater the number of pixels, the finer the detail that can be resolved (Fig. 2.3).

A larger computer file is required to describe a larger collection of pixels. In telemedicine applications, the quest for larger files that produce finer clinical details must be balanced with telemedicine transmission requirements that favor more compact files.

For more tonal variety, each pixel can be expressed using multiple shades of grey. The number of shades represented is called the *bit depth* of the image. If only pure black and white are used to create the image, then the bit depth is two (Fig. 2.4).

Current international computer standards define an eight-bit system with 256 (2^8) different shades of grey as possible at each pixel. More expensive 16-bit (2^{16} or 65,536 shades of grey) imaging systems are commercially available, but their expense limits their use to specialized applications. Just as black and white bit depth affects ability to represent small changes in grey scales, the bit depth of color images affects ability to distinguish subtle colors.

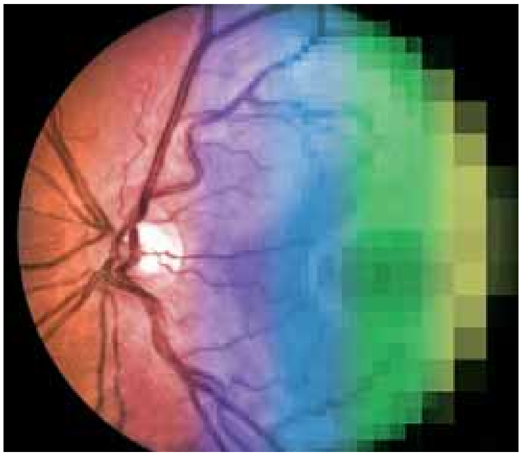

Fig. 2.3. Detail in this retinal photograph decreases from left to right as the relative size of the pixels increase, and the relative number of pixels decrease. Larger numbers of pixels usually mean greater detail

2.2.2 Color

Designating each pixel to one of three additive primary colors creates a color digital image, with the eight-bit gray scale image providing a building block for the 24-bit color image (there are eight bits each for red, blue, and green channels). This is accomplished on the digital imaging chip by overlaying a matrix of colored filters. The Bayer Mosaic (BM) describes the pattern used most often: a green pixel is alternated with either red or blue in the horizontal and the vertical direction (Figs. 2.5 and 2.6).

In most circumstances, the green channel resolves the finest detail; red contains the next largest amount of information; blue the least (Fig. 2.6). Two circumstances prevent the preponderance of green pixels from overwhelming information from the other colors in the final image. First, the information from each pixel is recorded in two ways: as an absolute value (white, light grey, dark grey, black) for that particular pixel, and also as a color driven value (white, light green, dark green, black). The camera digitally processes the image before it is output to the display device; at this point, it assigns green, red, and blue values to each and every pixel based on either the actual pixel value, or on extrapolated values obtained from information inherent in adjacent pixels. The result is a more color-balanced output to the monitor that uses evenly alternating green, red, and blue points to convey the information.

If a single color is represented in the computer by one of 16 million Red, Green, Blue (RGB) values, then the universe of these values can be defined as the “color space.” The Commission Internationale d’Eclairage (CIE) color model represents a standard set of color values (referred to as the *human eye’s color space*) [2] as perceived by most normal-sighted individuals. Digital imaging (and also film) is physically unable to adequately represent each and every color within this set. The two most common color spaces used in digital imaging are subsets of the larger CIE color space: Adobe RGB 1998 and sRGB.

In Fig. 2.7, notice that Adobe RGB contains additional sensitivity in the green area of the spectrum. These color spaces describe values that are available in digital color sensors and color monitors that use the RGB model; they are not

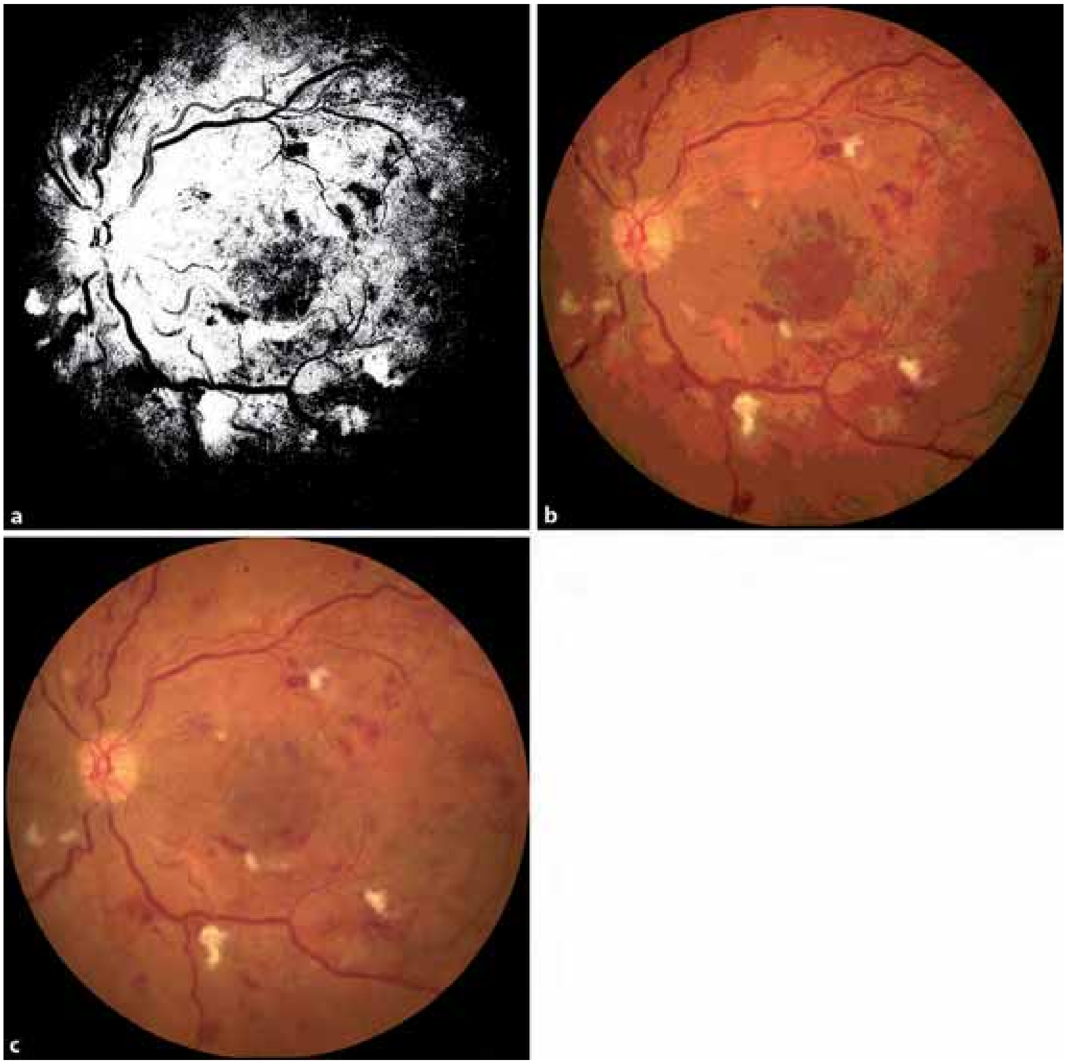

Fig. 2.4. Comparison of the ability to distinguish fine color gradations and bit depth as it increases from (**a**) two bit (pure black + pure white) to (**b**) four bit ($2^4 = 16$ colors) to (**c**) 24 bit ($2^{24} = 16\,777\,216$ different colors)

available in printed material that uses the CMYK (cyan, magenta, yellow, and black) color model.

It would seem that defining color using a numerical-based system would further our pursuit for precision and color accuracy. But different sensors and different monitors may represent the same numerical value in different ways – in the same way that different films from different manufacturers, different films from the same manufacturer, and even different emulsion batches of the same film from the same manufacturer, register colors slightly differently. Calibrating color input (camera settings) and output (monitor settings) at all telemedicine sites is an important step toward ensuring that all involved parties are making decisions based on similar visual information.

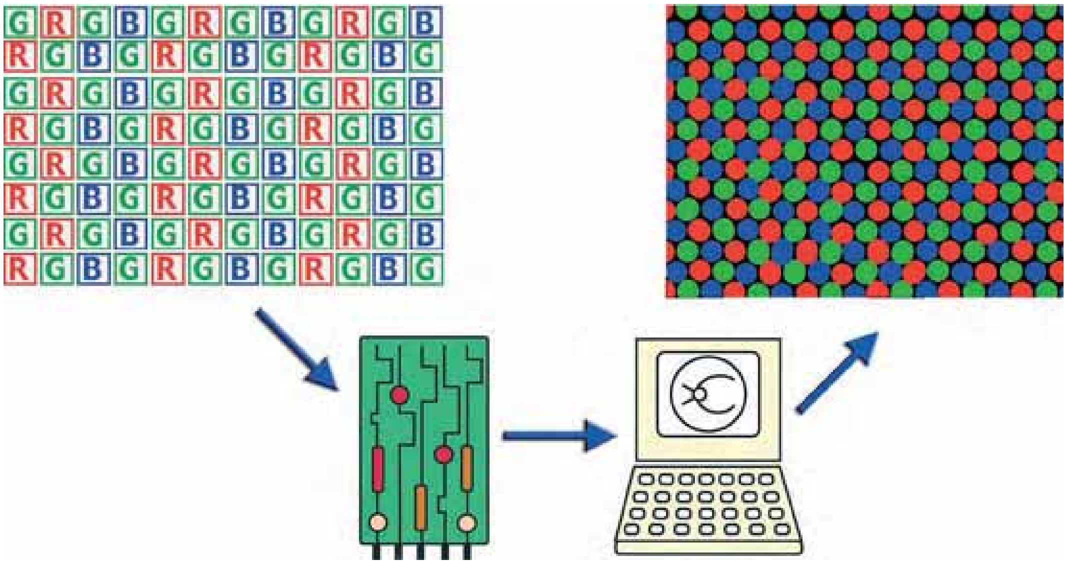

Fig. 2.5. Digital camera-based example of captured information using the Bayer pattern – a checkerboard design with 50% green, 25% red, and 25% blue filters (*left*). The computer interpolates this information and outputs it in equal parts of green (33%), red (33%), and blue (33%) (*right*)

2.2.3 File Formats

Each image, description of physical space, and set of directions for making a picture must be compiled so that the information can be easily read on multiple computers. This writing convention is defined by the *file format* of the image. There are literally hundreds of different file formats in use today. The four most popular formats are: .tif (Tagged Image File Format, TIFF); .jpg (Joint Photographic Experts Group, JPEG); .pdf (Portable Document Format, PDF), and; .gif (Graphic Interface File, GIF). Files written in the .tif format are usually large, because each separate pixel is individually described. A 300 pixels-per-inch .tif file to size is the standard requested by most high quality, glossy publications. A .jpg file is a *lossy* compressed image file, and it does not contain all of the information of the original image description. The .jpg compression standard calls for first deleting non-critical information by rounding and removing redundant information, then ordering the information using Huffman encoding, converting to sRGB color space, and sub-sampling. Artifacts can be easily seen when high .jpg compression ratios are used (Fig. 2.8).

A 72 pixels-per-inch .jpg file to size is the web publication standard, while a 1,000 pixel by 750 pixel .jpg file is the standard for PowerPoint and similar electronic presentations. A .pdf file, which is really a combination of files that was developed for the publishing industry, combines text information with .jpg images. Optical coherence tomography is an example of an ophthalmic instrument that can output information in .pdf format. A .gif is a pixel-based file format that incorporates *dithering* to make the most of its minimal eight-bit (256 colors) range. This format is widely used for small web graphics, but is rarely used to convey ophthalmic information. Table 2.1 summarizes common file formats and their uses.

2.2.4 Data Compression

An important imaging concept is the relationship between the amount and type of image compression and the quality of the information that is transferred. The speed of information transfer is called *bandwidth*. Because bandwidth is limited, telemedicine image files are often compressed,

Fig. 2.6. Three individual channels – green, red, and blue – that compose a color .tif image. Each channel contributes specific tonal information to the final image

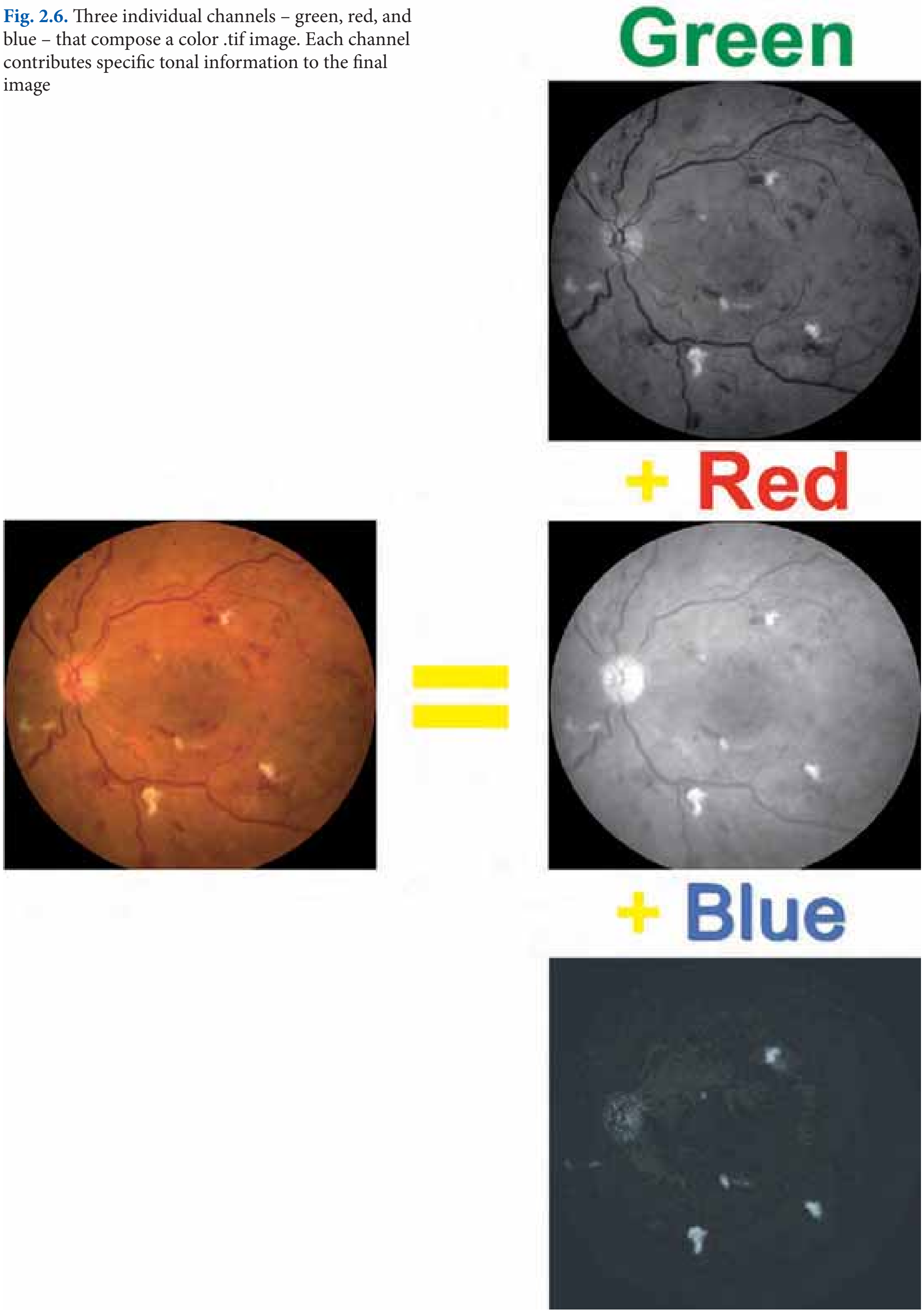

Table 2.1. Common file formats and their uses

Image type	File use	Preferred format	Comments
Continuous tone photograph	Archived master image	.tif, raw	Highest available resolution
Continuous tone photograph	Publication	.tif	300 DPI at printed size
Continuous tone photograph	Presentation (PowerPoint)	.jpg	100 DPI sized at 10 × 7.5"
Continuous tone photograph	E-mail, WWW	.jpg	72–96 DPI at screen size
Line-art/graphic	WWW	.gif	Low bit depth format
Document with text and images	Electronic distribution	.pdf	Not for archiving: uses .jpg images

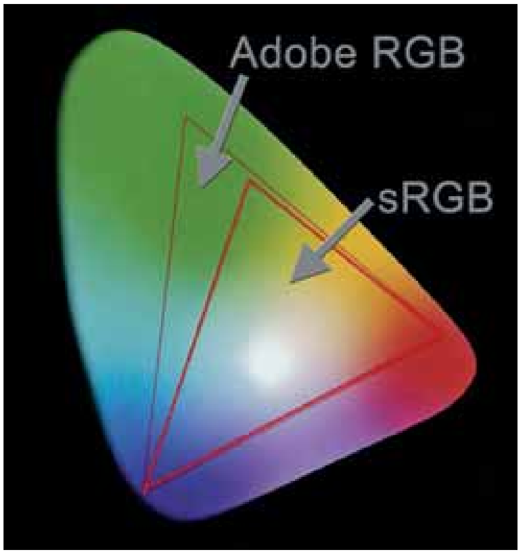

Fig. 2.7. Example of Commission Internationale de l'Eclarage (CIE) color space, which represents the full range of color seen by a standard human observer. Color digital imaging can represent a subset of these colors by implementing either the smaller sRGB color space or the larger Adobe 1998 color space

which reduces image file size. This can be accomplished in one of two ways: via *lossless* or *lossy* compression schemes. The following analogy explains the difference between the two. Imagine conveying the information contained in the image of this page of text. You could list the letters involved, include their size and order, define the space they take up as black, and then specify that the rest of the image is white. This set of directions is likely to be smaller than specifying each and every data point in a pixel based image file of the page. When the image is reconstituted, this lossless compression will convey the same information as the original image of the text page.

A second lossy method of compressing the same information might assume that the letters *i* and *l* look very similar, which makes it possible to replace each *i* with an *l*. This reduces the number of different letters involved, making the resulting file smaller. As this letter replacement compression scheme continues, the letters *n* and *m* can be paired, as can the letters *d* and *b*; *c*, *e*, and *o*; and so on. As letters are continually replaced, the meaning of the original page becomes more and more difficult to read, which is a problem that is inherent in implementing lossy compression. While ophthalmic images certainly can be compressed to very small sizes that are easy to transfer, care must be taken that the information to be conveyed is not lost in the process.

The problem of using image compression to reduce the size of medical images has been researched by a number of specialties – with varied results. For instance, Koenig studied dental lesions and concluded "JPEG compression does not impact detectability of artificial periapical lesions at low and moderate compression ratios up to and including 28:1" [3]. A recent paper by Stellingwerf concluded "the compression of the digital images seems to have some adverse effect on the detection of diabetic retinopathy" [4]. Beal's radiology study concluded "five of six radiologists had a higher diagnostic accuracy when interpreting uncompressed chest radiographs versus the same images modified by 10:1 lossy

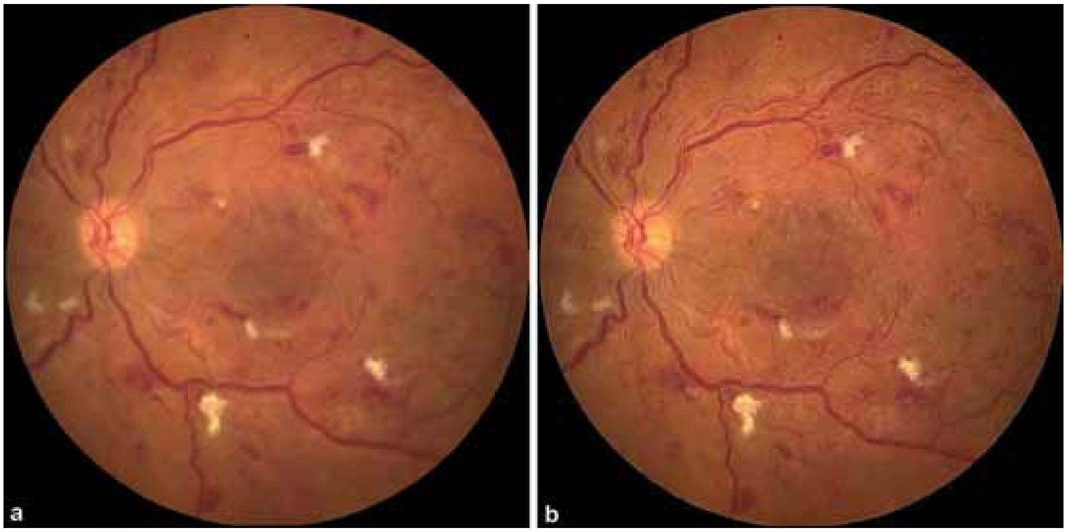

Fig. 2.8. Proper resolution fundus photograph with lost sharpness and color because: (**a**) of overcompression using a lossy file formator (**b**) multiple saves in lossy compression formats degrades images

compression, but this difference was not statistically significant" [5]. Because digital imaging compression is still an evolving technology, expert clinical judgment may be the best guide in resolving limitations.

2.3 Digital Ophthalmic Photography Instrumentation

Ophthalmic imaging encompasses a wide range of photographic modalities, each of which is designed to capture a specific type of visual information. General cameras with macro lenses are used to image oculoplastic conditions and strabismus. Slit lamp cameras illustrate the anterior segment, and fundus cameras image the posterior segment [6, 7].

2.3.1 External Photography

External ocular photography documents the external eye, lids, and ocular adnexa. Professional grade digital cameras with high quality, close focusing capabilities are required. The challenge of external photography is that it appears to be so easy. But unless careful steps are taken to accurately capture visual information such as tissue size, color, position, asymmetry, motion, and modification, photographs could display false color, distorted perspective, or insufficient information.

Preferred camera angles, magnification, and backgrounds should be standardized during the image capture process. Specific digital camera recommendations quickly become outdated as the industry continues to evolve at a rapid pace. The lowest priced digital single-lens reflex (SLR) camera that is compatible with traditional film SLR lenses is currently priced below US$1,000. These 6–14 megapixel cameras provide appropriate color reproduction and resolution for medical imaging projects. Large image files should not be a cause for concern if the computer and storage media is kept up to current specifications.

The purpose of the image also affects the choice of capture resolution. For instance, a publication quality 7"×10", 300 dots per inch (DPI) .tif file requires a six megapixel capture, while a screen resolution (web/PowerPoint use) 7"×10" 72 DPI image requires only a one megapixel capture resolution.

Inexpensive consumer cameras (1–2 megapixel) should be avoided, as their low pixel res-

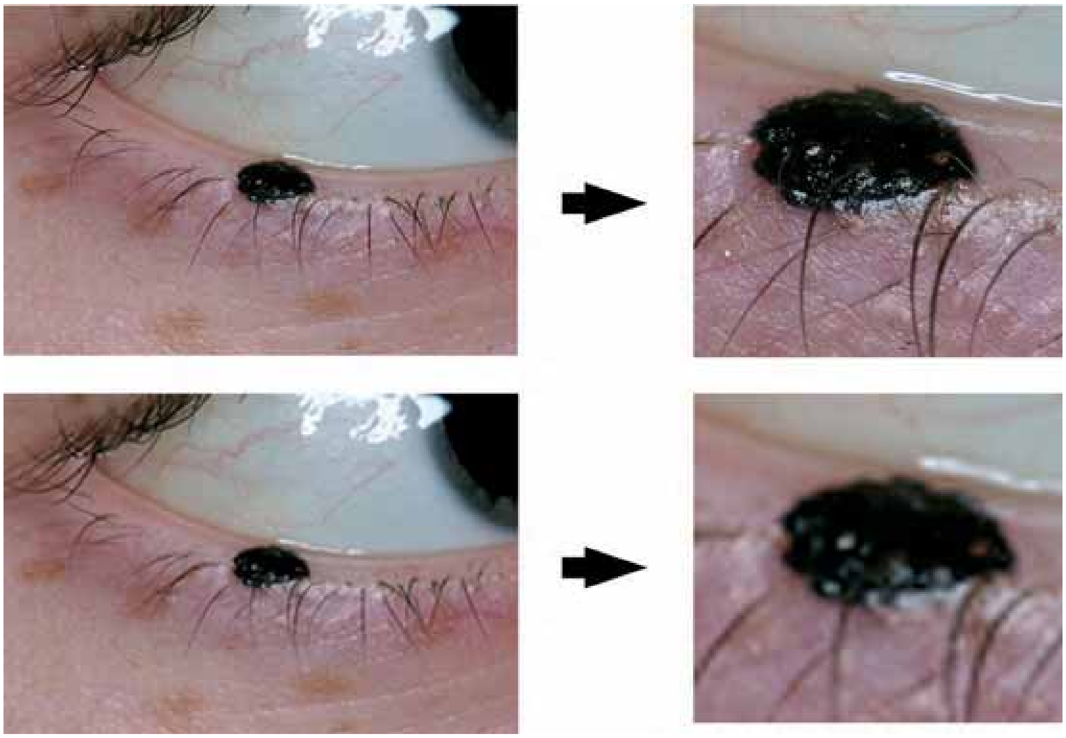

Fig. 2.9. High resolution, eight megapixel image of lid lesion loses little when enlarged (*top*), while the enlarged one megapixel image loses contrast and detail (*bottom*).

olution will not adequately capture fine detail (Fig. 2.9).

A mid- or high-range rangefinder-type consumer digital camera (4–8 or above megapixels) may be useful; however, the suitability of the camera's macro focusing function should be checked for any wide angle distortion when focusing closely. Other considerations are the electronic viewfinder of the digital camera, which can be used to overcome any parallax error that may be evident in the optical viewfinder; the ease with which settings can be changed; and the ease with which appropriate image download and transfer procedures can be planned.

2.3.2 Imaging the Anterior Segment

A photo slit lamp is required to image the anterior segment. While standard cameras may provide adequate magnification, it is effectively capturing the slit illumination that maximizes the information.

There are essential technique differences between corneal examination and slit lamp photography. The slit lamp examination is a dynamic process. As you drag the slit across the cornea, changing the illumination, magnification and angle of approach, making these and other fine adjustments – a synopsis or a *movie* of the cornea is created. The final impression gained after a slit lamp examination is not based on any single view, but is rather an accumulation of the pertinent details. Slit lamp photography, on the other hand, is by nature a detail. A slit lamp photograph is a *snapshot*. It is information from a single moment; a single frame from the movie. While this limitation can be overcome by using multiple photographs to tell a *picture story*, each single photograph is still limited to conveying a single visual statement.

Fig. 2.10. Vintage Zeiss photo slit lamps can be converted to effective digital telemedicine tools by integrating new digital single lens reflex camera bodies

Subtle differences in color and detail exist between corneal examination and photography. The dynamic range appreciated by the examiner at the slit lamp is much greater than the dynamic range that can be captured digitally. This means that structures outside the slit beam that may be quite visible while viewing through the oculars are very dark and indistinguishable when recorded with the camera. The photo slit lamp's background illumination flash adds fill light, which helps to brighten the shadow areas of the image, creating photographs that more closely resemble the cornea during a slit lamp examination.

Multiple instruments are available for anterior segment imaging. The lowest tech solution is to adapt a digital snapshot camera to a standard slit lamp [8]. To do this, the digital camera should be focused on infinity, and aligned to the ocular; the camera's liquid crystal display (LCD) should be used to monitor the image. Note that this method may be awkward in practical terms. To compensate, an adapter may be constructed to facilitate alignment.

Another solution is to refurbish a traditional Zeiss photo slit lamp. While this unit is no longer manufactured, it was popular for years, so is still generally available (Fig. 2.10). The film SLR body can easily be replaced with a newer digital SLR body [9]. Alternately, both Haag Streit and Topcon have recently introduced digital photo slit lamps (Fig. 2.11). Video based slit lamp imaging instruments generally have too little resolution for quality work. By increasing magnification and capturing several fields it is possible to overcome limitations of resolution with video capture. For example, by setting magnification to 40× on a Haag Streit BQ slit lamp, the 640 × 480 resolution is comparable to a higher resolution image from a Haag Streit BM slit lamp; however, illumination must be increased in order to capture higher magnification images.

If only a few images are required, and image quality is not critical, the slit lamp light source should be turned to its maximum setting and photographed with a close focusing hand held digital camera. At the same time, the color balance should be set to *tungsten* to avoid yellow images. Multiple images may be required to obtain the best focus and proper composition.

2.3.3 Imaging the Fundus

The optical instrument used to visually document the retina is called a fundus camera. Fundus cameras are often described by the angle of

Fig. 2.11. Newer photo slit lamps, like this Topcon SL-D2, incorporate a digital camera that writes directly to a compact flash card (*arrow*) (image courtesy of Topcon America Corporation, Paramus, New Jersey)

view – the optical angle of acceptance of the lens. An angle of 30°, considered the normal angle of view, creates a film image 2.5 times larger than life. Wide-angle fundus cameras image between 45° and 140° and provide proportionately less retinal magnification. A narrow-angle fundus camera has an angle of view of 20° or less. Normal-angle cameras have smaller illuminating annuli, making them more suitable for patients with pupils of a smaller diameter. The inner diameter of the illuminating ring in wide-angle cameras is larger, which makes it harder to photograph patients with small pupils.

Fundus cameras can be described as either mydriatic and non-mydriatic. Mydriatic fundus cameras require pharmacologic dilation, while non-mydriatic fundus cameras use an infrared viewing system to exploit the patient's natural dilation in a dark room. Infrared light is used to preview the retina on a video monitor. Once the monitor's image is focused and aligned, photographic technology takes over: a flash is fired and the image is exposed. Most users describe more consistent photographs when patients have been dilated with 1% Mydriacyl (tropicamide) [10].

The non-mydriatic fundus camera was pioneered by Canon in the late 1970s, and by the mid-1980s, Canon, Kowa, Reichert, and Topcon were marketing various models. The typical angle of view of a non-mydriatic fundus camera is 45°. While traditionally used for screening purposes, newer diabetic screening devices (DSD) substitute digitally databased electronic images for traditional Polaroid and 35-mm film [11]. Currently available *non-myds* use 1–8 Mb digital chips to capture retinal images. Images are displayed on built-in LCD monitors and output to compact flash memory cards (CFMC) or a database via a universal serial bus (USB) connection. An advantage of these newer models is that their small chips function better in lower light levels than traditional film, making the flash less bright and maximal dilation less of an issue.

Still, it's a good idea to keep two spare viewing lights, flash tubes, and fuses readily available.

The fundus camera's instruction manual will contain detailed installation procedures. Fundus cameras that are used daily should have yearly inspections by factory-trained technicians. Alternately, contact the manufacturer's technical representative, and consider returning the camera to the factory for complete optical realignment and refurbishment every 5–10 years; mobile cameras may need service more often.

A medium-priced multiple-angle fundus camera offers respectable sharpness in a variety of optical angles and is suitable for a general ophthalmic practice. Built for performance first and price second, the normal-angle fundus camera is favored by the retinal specialist, because it is designed to produce sharp photographs of the macula, which it does extremely well. Its small illumination doughnut facilitates photographing through narrow pupils, and the astigmatic compensation device is useful for far peripheral views. Special-use fundus cameras include: extreme wide-angle, simultaneous stereo, and hand-held fundus cameras. If no angiography is involved, a digital non-mydriatic fundus camera is a good choice for telemedicine (Fig. 2.12).

Fig. 2.12 a.

Fig. 2.12. Fundus cameras that are new, whether standard angiography models (**a**) or non-mydriatic (**b**), are available with digital output. Some models were developed specifically for telemedicine applications. Images courtesy of Carl Zeiss Meditec, Dublin, California (**a**); Canon USA, Lake Success, New York (**b**); and Topcon America Corporation, Paramus, New Jersey (**c**)

Fig. 2.12 c.

Most new fundus cameras are available as digital imaging instruments. Recent instruments (1998 or newer) and the widely available Zeiss FF series fundus camera can usually be converted from film to digital imaging [12].

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