ORIGINAL ARTICLE

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Creating Retinal Fundus Maps

Abstract

A 'Fundus Map' is a computer generated montage combining multiple adjacent retinal images. It is useful for illustrating large retinal areas. This article describes the history, ethics and methods of producing large area fundus images, and concludes with a tutorial on constructing your own fundus map using Adobe® Photoshop®.

KEYWORDS

Fundus map, wide-angle fundus photography, Adobe® Photoshop®, history of ophthalmic photography, creating retinal fundus maps

Traditional fundus photography is a useful tool for documenting a variety of retinal changes. But because of the relatively small retinal area covered, fundus photography presents a challenge to physicians and ophthalmic photographers when describing large and diffuse retinal diseases. The "fundus map", a computer-generated montage of multiple adjacent retinal images, is able to illustrate large areas of retinal disease.

FROM OPHTHALMOSCOPY TO PHOTOGRAPHY

Viewing the fundus through the pupil is like looking through a keyhole into a large room. You can easily see straight across the room, but to view a greater area, you must rotate your perspective in relation to

the keyhole aperture (Figure 1). During the dynamic examination process, the ophthalmologist conceptually pieces together isolated retinal views into a single impression of the retina in their mind's eye. The tunnel vision of a keyhole aperture and the static nature of a single fundus photograph can make the peripheral retina difficult to fully appreciate photographically.

The optical angle of acceptance of a fundus camera lens is described in degrees.[1] The first commercially available fundus camera, introduced in 1926 by Carl Zeiss, featured a 20° angle of view. This smaller image circle is now considered a 'magnified view', used to record foveal and optic nerve details. The familiar Zeiss FF series fundus cameras, available from the 1950's to the 1990's, popularized the 30° angle of view. This became known as the "normal" angle of view, and is useful for documenting the macula, optic nerve and small areas of the periphery. Specific overlapping 30° views ("seven standard fields") were developed in the early 1960's by multicenter clinical trials to record diabetic retinopathy changes in the mid-periphery[2] (Figure 2). In 1970, Nikon introduced the first 'wide angle' fundus camera (45°).[3] Kowa created the first variable angle model (RC-WVF: 45°-30°-20°) in 1976. Fundus cameras in common clinical use today feature variable, wide angle lenses which range from 15° to 60°.

A 60° camera covers a larger area than a 30° camera, but also demands a larger pupil, and is more
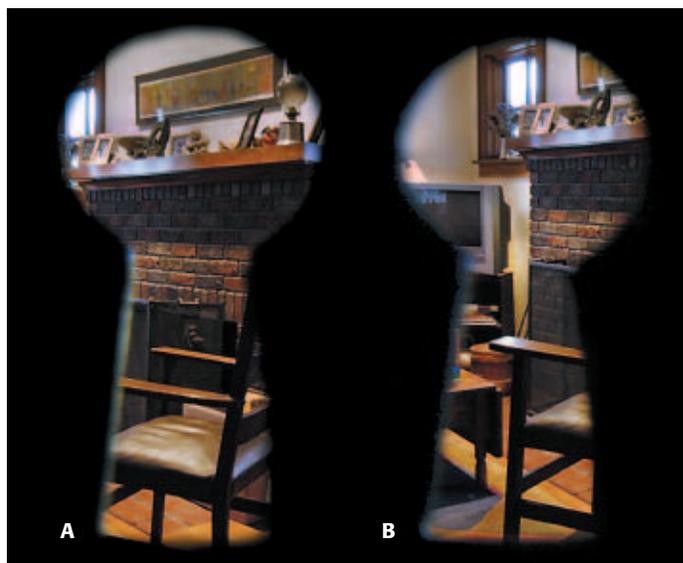

Figure 1: The limited view through a keyhole aperture as seen directly (A) and rotated (B).

prone to pupillary induced artifacts than the 30°. As the camera and eye are rotated away from each other to capture the far periphery, the net effect of the pupil size is reduced, making it more difficult to control flare from the camera's central cone of light (Figure 3). At the same time, a larger area of the inner globe is mapped to a smaller area of flat film, increasing distortion. Consequently, the 30° camera often can record farther out in the

periphery than the 60° camera. But while it can be easier to photograph the far-periphery with the 30° camera, many more images must be recorded to achieve complete coverage.

Fundus cameras with extremely wide angles of view have been manufactured. The 150° Equator Plus/Pomerantzeff and the 100° Clinitex (1980) contact lens cameras are early examples.[3,4] The Equator Plus illuminated the retina using a fiberoptic probe placed on the sclera. Neither camera gained wide usage because of mediocre image quality.

Current wide angle camera designs include the Massie Research Retcam 120 (Dublin, CA) which is designed for retinal imaging of the pediatric patient. This digital contact lens camera features interchangeable lenses and angiography capability. The Medibell Panoret (130°) uses trans-scleral lighting. These digital cameras can provide excellent wide angle images in the hands of a skilled operator (Figure 4).[5]

Another useful wide-angle photographic technique involves imaging the retina with auxiliary lenses. Deguchi, et al, have had success using 90° and 100° magnifying lenses in conjunction with a 60° fundus camera. Gilman describes using the Rodenstock Panfundascope at the photo-slit lamp.[6] Clark[7] has increased the angle of view during angiography by using indirect lenses in conjunction with a 60° fundus camera.[8]

Previous photographic attempts to reproduce this larger conceptual image consisted of cutting and pasting together photographic
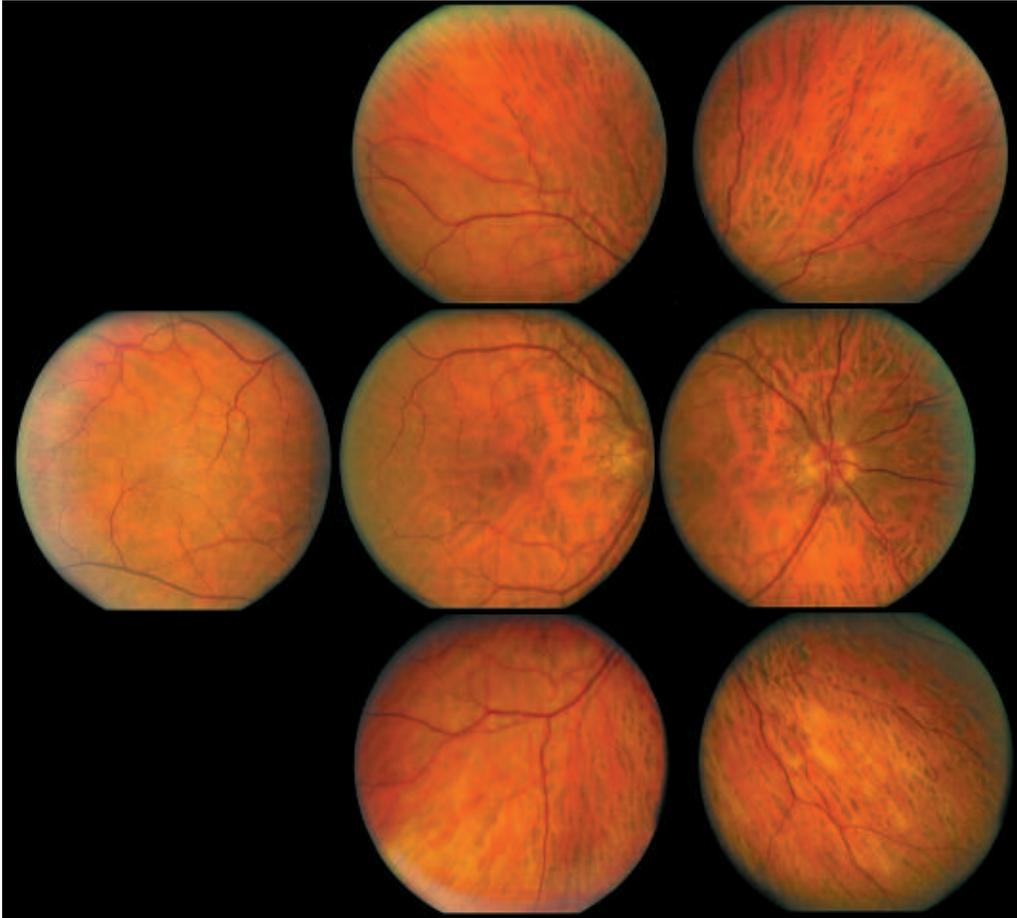

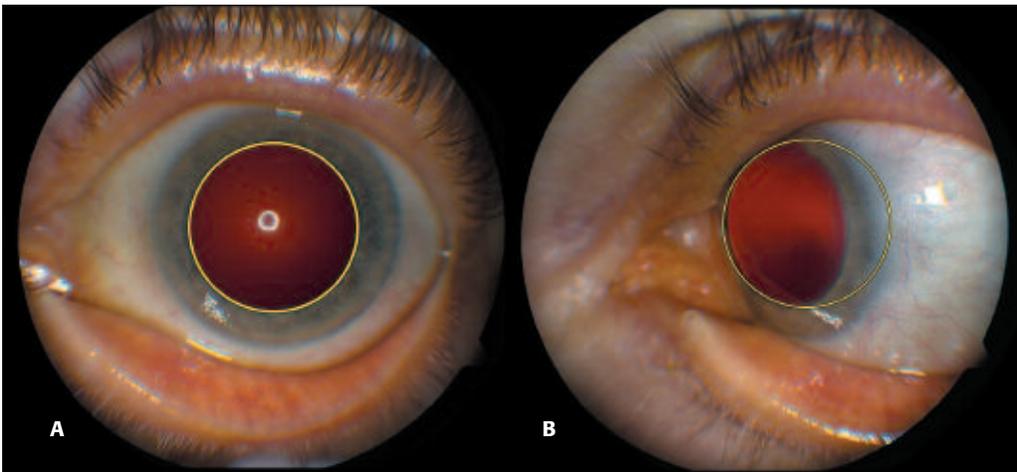**Figure 2:** The seven standard fields, taken with a 30° field of view Zeiss camera.

Figure 3: A pupil dilated to 9mm when viewed directly (A) is larger than when the eye is rotated for imaging the retinal periphery (B).
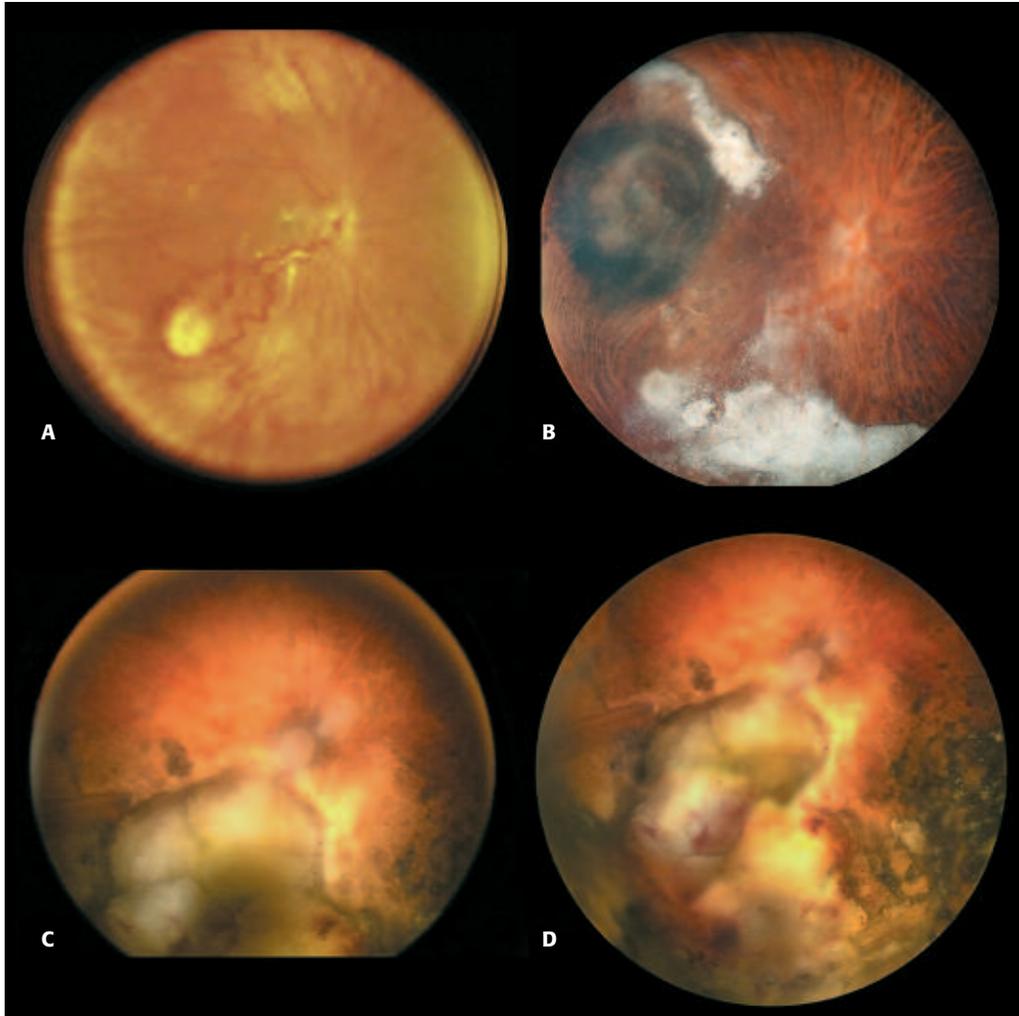
Figure 4: Examples of images from Equator Plus (A), Panoret 1000 (B), and RetCam (C) cameras. Figure 4D is a fundus map from the same patient using the RetCam.
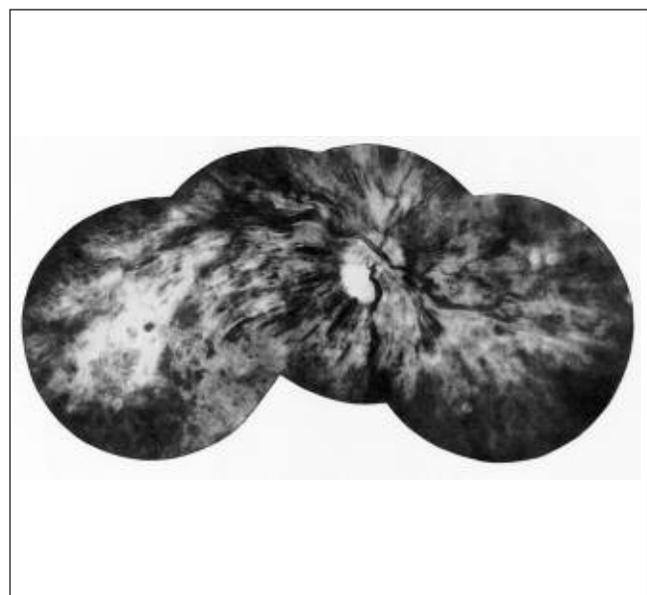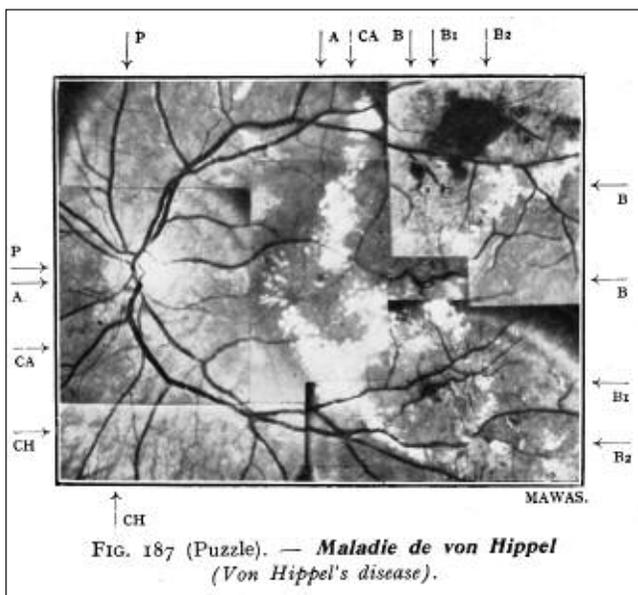

Figure 5: Retinal image montages consisting of overlapping prints have been published in previous atlases including (A) Atlas Clinique D'Ophtalmoscope Photographique by Tille and Couadau page 183 (Paris: Masson et Cie, Editeurs, 1939) and (B) Studio Documentato del Fondo Oculare by Clerici page 162 (Milano: Casa Editrice A. Fattorini, 1957).

prints of multiple adjacent views of diffuse retinal diseases (Figure 5). This technique suffers from the problems inherent in the basic challenges of fundus imaging. Color, contrast, and tonal aberrations are often apparent along the edges of fundus photographs. The intersection of joined images is precisely where the limits of the optical system are most evident. The distorted perspective caused by the curvature of the ocular fundus presents its own challenges. Cartographers encounter a similar problem when transferring the globe-shaped earth onto a two dimensional map. In 1569, Gerhardus described certain distortions that must be accounted for and transposed when translating the components of a globe onto a flat surface.[9] Similarly, the curved surface inside the globe of the eye, the retina, must be understood in its relation to a flattened illustration of it.

As computer imaging matured during the 1990's, standard image-manipulation software (Adobe® Photoshop®, San Jose, CA) made seamless composites of digitized photographic images possible. In 1995, Hackel was the first to publish a computer generated retinal montage from multiple images.[10] The original photographs were taken by Alan Frohlichstein using a 30° fundus camera. Frohlichstein had originally submitted a cut-and-paste composite for consideration to *The Journal of Ophthalmic Photography*. The 92 original photographs were consequently scanned and integrated by Hackel into a computer-generated montage. (Figure 6) The resulting image was named a "fundus map" by Richard Hackel and Marshall Tyler who worked collaboratively on the concept. A similar technique has subsequently been described in the ophthalmic photography literature.[11]
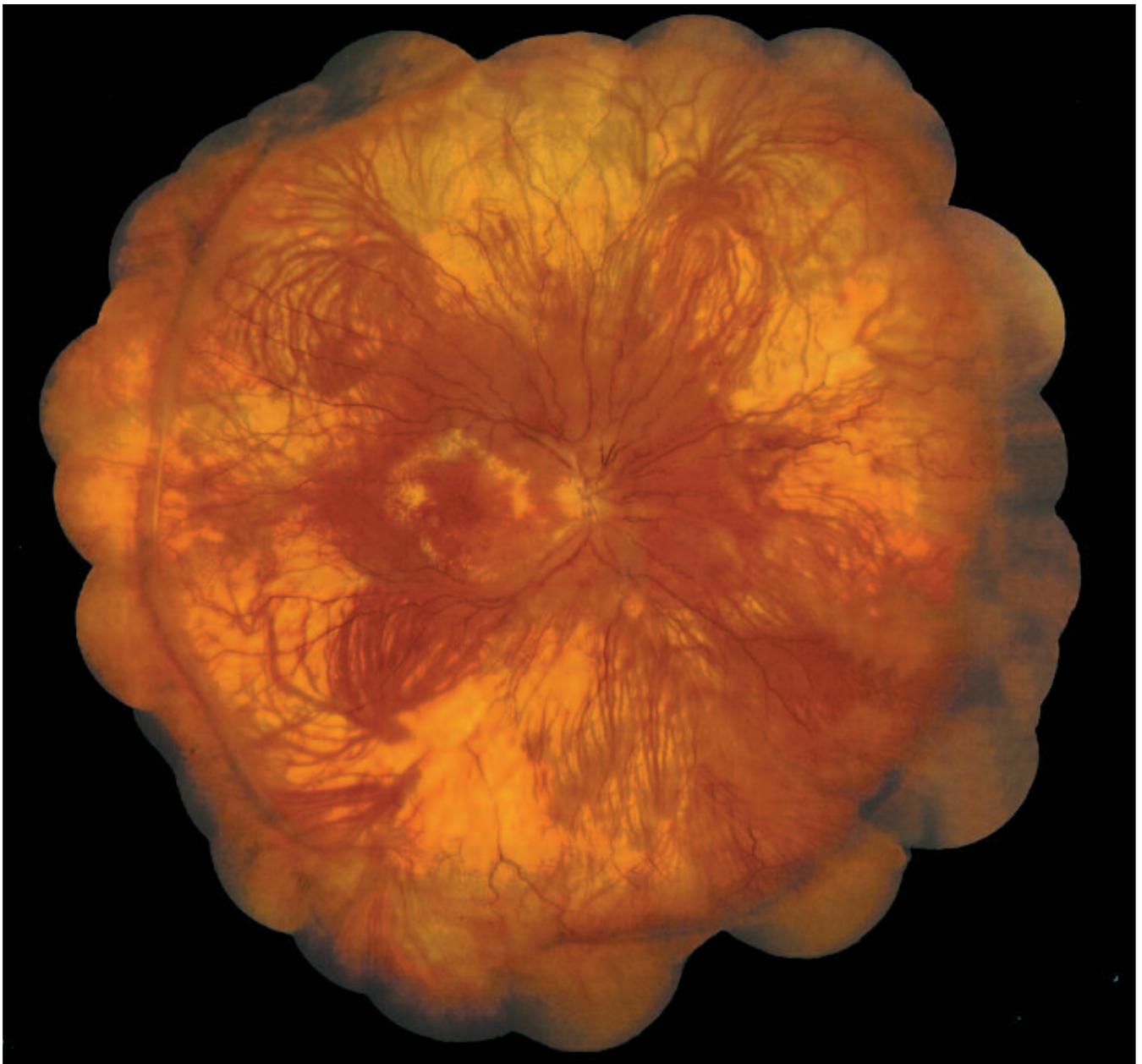

Figure 6: Cover photo-illustration for *The Journal of Ophthalmic Photography*, Volume 17, #2 (Spring 2004).

Photography has historically been acknowledged as a documentary medium and has regularly been used by medicine to provide visual evidence.[12] With the widespread introduction of digital imaging and image editing software, conventional wisdom suggests that photographs are somehow less truthful because it is now so easy to modify images. However, while the current ease with which digital images can be manipulated may raise suspicions about the reliability of information, the photographic process itself has always involved some degree of interpretation. Editing, composition, film, paper and chemistry decisions all affect the information presented in the final image. For example, to make a print from a negative, a photographer must make calculations and compromises to account for the shorter tonal range inherent in the paper print, as compared to the original camera negative. Ansel Adams described that transparent film viewed with transmitted light offers much more tonal information than a paper print viewed with reflective light.[13] Consequently, any print made from a negative must be interpreted to accommodate for this reduced tonal range.[14] Dodging and burning is often needed just to maintain a basic relationship between the highlights and shadows in a print. All prints represent a limited interpretation of the original data found in the negative. In film-based fluorescein angiography, the original negative contains more accurate tonal information than either a transparency or paper print.

Making fundus maps was initially a slow and labor-intensive process because of slower computer processing speed and the high cost of computer memory. Technical improvements over the past eight years have reduced both the time and cost required. For example, the first computer generated montage took over 40 hours to piece together on a high-end Macintosh Quadra computer running Photoshop® 3.0 software. Using the same techniques, with file sizes that are much larger, that same image can now be re-created in as little as two hours. The process has also been made more efficient by utilizing original digital retinal images which do not require the additional step of being digitized like the film-based photographs. This eliminates residual artifacts (dust and scratches) that are a common problem in the film-to-digital conversion process. While intense computer work is still required to create seamless, visually attractive images, the process is now much shorter.

As with all fundus imaging, media opacities, pupil size, and poor patient cooperation can interfere with obtaining even a single good picture. Compound this with the requirement of multiple overlapping views and the practical results may contain numerous artifacts that are very time-consuming to correct. The final purpose of a montage often determines how much additional time is warranted when correcting for these artifacts.

TECHNIQUES AND TECHNOLOGY

The software of choice for maximizing the photo-illustration effect is Adobe® Photoshop®. Photoshop® is a pixel based image editing software which supports layers, channels, and professional color management. Among its many advantages is the ability to retain excellent detail and handle large files. Photoshop® allows disparate elements to be combined seamlessly, making composite images with split-focus or tonal shift look more natural. Its main disadvantage is that it is very time consuming and requires a steep learning curve. It is not medicine-specific software, so image accuracy is dependent on knowledge of pathology and procedures. Figure 7 shows an example of how the final shape of a round scleral buckel can be interpreted by the photographer.

For more efficient clinical work, automated stitching software packages are available from a number of vendors. These include the Carl Zeiss VisuPac Montage Module and the Topcon Mosaic 2000. Their main advantage is speed, making mapping easier to incorporate into a clinical workflow. However, they tend to be less accurate with color balance and tonal blending between frames. A hybrid technique can be used to even out the results: automated software is used for the initial composite after which residual artifacts are eliminated in Photoshop® (Figure 8). Ophthalmic Imaging Systems has recently introduced new software, AutoMontage, that incorporates almost total automation of combining images and edge blending. While fast and clinically useful, the images can also still benefit from post-processing in Photoshop.

PHOTOGRAPHING FOR A FUNDUS MAP

Before making a fundus map, whether manually in Photoshop or automatically with stitching software, you will first need to adequately photograph all appropriate retinal fields. It is generally a good idea to overlap frames by 30% to obtain enough area to blend. As you work farther out in the periphery, you will notice more pictures are required to cover the same area, compared to more central areas. It is often useful to take two photographs of the same field, each focused differently to account for different planes of sharpness or different levels of pathology. These differently focused images can then be blended together into a single sharp image, giving the impression of a greater depth of field (Figure 9).

In the struggle to acquire as many fields as possible, small segments of retina are easy to miss. These gaps between fields can result in small empty patches while piecing the montage together. To enhance the final presentation, these small areas of retina can be patched over (Figure 10). Since these areas contain no clinically significant findings, this process does not alter the accurate presentation of the disease. We would like to point out that once this relatively easy trick is mastered, it is also a simple matter to change and correct areas that are clinically significant. In unscrupulous hands, this could be used to dishonestly illustrate a disease, or erroneously present a patient with a different disease (Figure 11). We strongly caution against manipulating data to change any
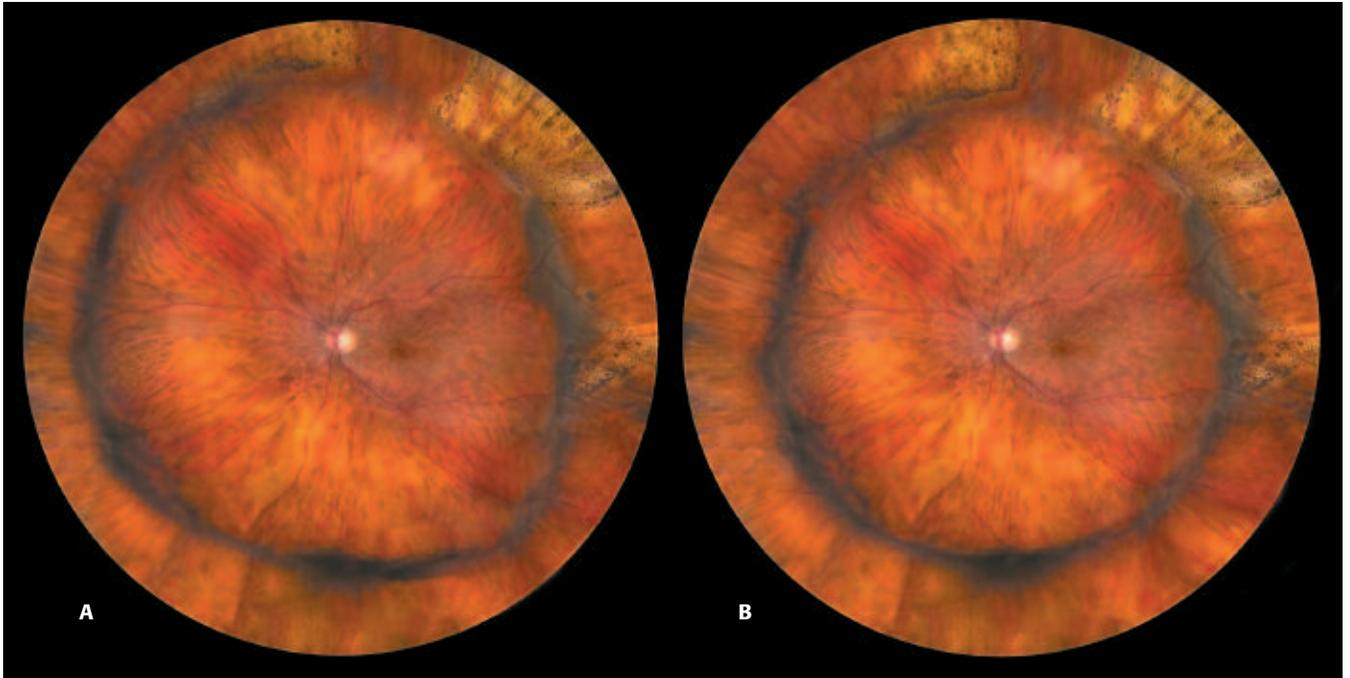
Figure 7: Two interpretations of a scleral buckle fundus map.

Figure 8: Ophthalmic Imaging Systems' AutoMontage software can make a fast, clinically useful composite (A) that can also be enhanced for photo-illustration (B).

Figure 9: A vitreous membrane is photographed in two different planes of focus. (A) shows the retinal surface in focus, (B) shows the membrane in focus, and (C) show the two combined into one photograph.
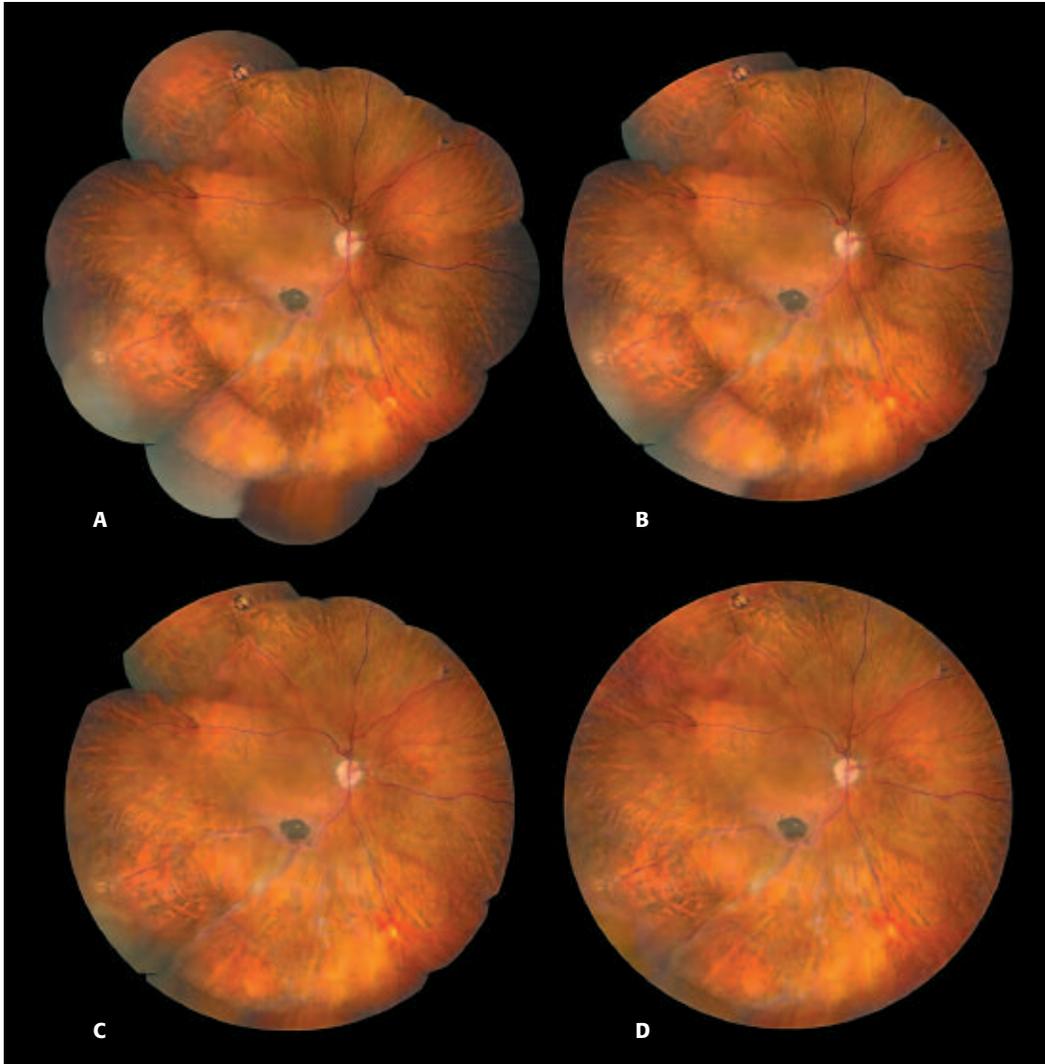
Figure 10: The initial fundus map (A) is cropped to form a circle (B), overlapping edge marks are blended (C). Small clinically insignificant areas of missing retina at the edge of the circle can be enhanced (D) to make a better photo-illustration.
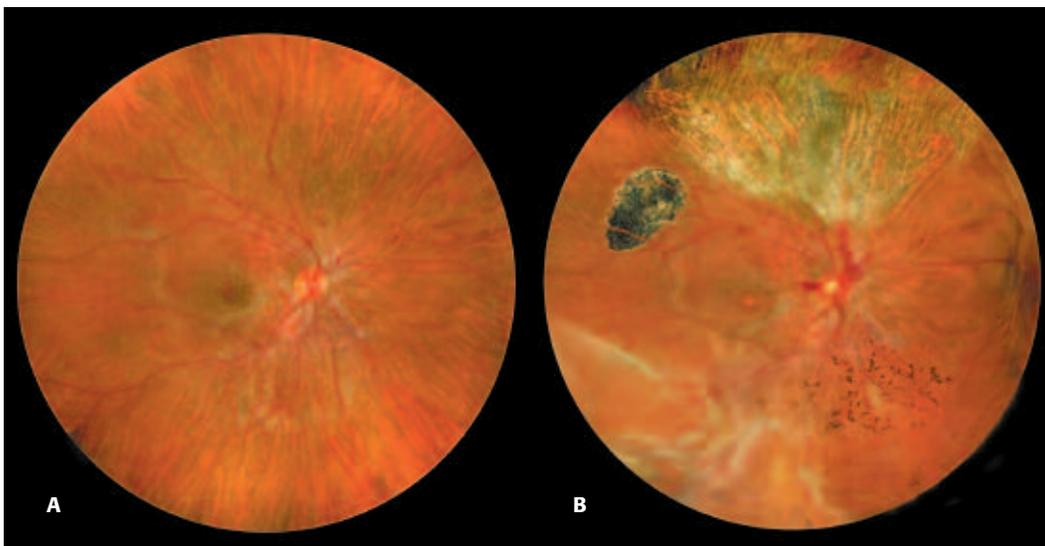

Figure 11: Fundus Map of a normal eye from a 14 year old female (A). The same eye (B) with seven added diseases. *(From Saine & Tyler: Ophthalmic Photography, Butterworth Heinemann 2003.)*

findings. As with any technology, manipulating images with the computer can be used to either enable deception or improve illustration.[15]

Each image for the fundus map must be in a digital format. If a digital fundus camera was used, just copy the images you plan to use into a separate directory. Most digital systems use a standard file format (.tif or .jpg) for patient photographs. Consult your users manual or the vendor's help desk if this is unclear. Film images need to be digitized. Scanning, re-photographing with a digital cam-

era, or copying with color negative film and requesting a Photo CD from the processor are all reasonable options.[16] Making each image 6-10 MB .tif file is a good starting point. Assuming approximately eight images in the final composite, this file size will provide enough data to make a publication quality (300DPI) 8x10 inch print. For more information on scanning, file sizes, and file format types, consult one of many good books on the subject.[17,18]

The tutorial section below gives specific step-by-step instruction for completing the fundus map.

The Adobe® Photoshop® Tutorial

This tutorial is designed to work with the image files down-loadable from the OPS website: ftp://www.opsweb.org. If you do not have a copy of Adobe® Photoshop®, you can download a trial copy from www.adobe.com for use in this exercise. This demo version will allow you to perform all the tasks required to create the fundus map; however you will not be able to save or print your work. This same technique will work with other image editing programs that offer similar features as layers, masks, and tonal adjustments.

Adobe® Photoshop® requires significant computer processing power and most modern computers are equipped to handle it. At a minimum, use a Macintosh G3 or Windows Pentium III processor, with 512MB RAM and a high-speed video card. A drawing tablet (Wacom: Vancouver, Washington) is also useful. By holding the stylus of the tablet instead of a mouse, the drawing components of this process are much easier to handle.

If you are not already familiar with the tools of Photoshop®, please spend some time familiarizing yourself with the tool-bars and pull-down menus before proceeding. It is strongly suggested that you preview this tutorial while an operating copy of Photoshop® is open on your computer.

Since there are many more tool palettes in Photoshop® than can comfortably fit on a computer screen, we suggest setting up your program only with the tools needed for this procedure. From the pull-down menu under Window, make sure the Tools, Options, History, and Layers palette windows are open. To save space, combine the Layers and History palettes into one. Close any other tool palettes.

You will be creating a composite image that consists of multiple layers. Each different image you add will create a separate layer. Each layer will be individually adjusted for alignment, tone and contrast. Creating files with multiple layers increases the working file size and lengthens processing time. However, avoid flattening or merging layers until the process is completed, as you will be adjusting layers both separately and in relation to each other. Near the end of the process you will flatten the layers then fix dust, scratches, and minor artifacts using the clone-stamp and healing brush tools.

1. In Photoshop®, select File>Open and open the image "01.jpg." This will be the central image for the final composite picture.

2. Increase the canvas size. This will make room for adding adjacent retinal images and approximate the finished size. First, make the background black (set default background colors by typing 'd', then type 'x' to switch the background from white to black). Select Image>Canvas Size: width: 12 inches, height: 10 inches. Using the pull down 'percent' option also works well. For example, if there are three images across, type 350 'percent'. If your images are two across plus one above and one below, then change both horizontal (250%) and vertical (350%).

3. Open the second image "02.jpg." Using the "Move Tool" tool (type 'v'), drag this adjacent image onto the new larger canvas. Look at the Layers palette and you will notice that a new layer, Layer 1, is automatically created. You can see the contents of this layer because the 'eye' is visible in the left most box of the layers palette. It is the active layer because it is highlighted. The paintbrush in the second box signifies that actions you take will affect this layer.

4. In the layers palette, change the opacity of this new layer to 50% (translucent). Using vessels as landmarks, align layer one with the underlying layer. Use the "Free Transform" command (pull down: Edit>Free Transform) to align vessels at the periphery. Stretch the image as needed by pulling on the image "handles" (small boxes at corners). Rotate, skew, and scale may also help align the layers. Once this new layer is in place, reset the opacity to 100%.

5. To seamlessly blend the images, add a "Layer Mask" either by clicking on the mask icon at the bottom of the layers palette, or by selecting from the pull-down menu: Layer>Add Layer Mask>Reveal All. Select the brush tool (type 'b'). Painting within the layer mask will either remove or reveal the image in this layer. Painting with a black foreground will remove the mask, showing the underlying layer. Painting with a white foreground will replace the top layer. Tap the 'x' key to quickly change the "Foreground/Background" between black and white. You may find various sizes of brushes useful.

6. Continue adding images (03.jpg, 04.jpg, etc.); aligning then integrating each image until the initial montage is completed.

7. When you are finished fitting the pieces together, work on balancing tones of adjacent layers. First make sure that within the layer you are working that you have selected the image icon and not the mask icon. In the Layers palette, click on the small thumbnail image (third item over). You will notice the second box from the left becomes a paintbrush. Clicking on the mask (fourth item from left) will replace the paintbrush with a 'mask' icon.

    Locate areas that seem unnaturally dark when compared to the surrounding retina. These are usually found near the edges of the original images. Using the lasso tool, draw a rough outline around the area to be corrected. If you were to now adjust tones, there would be a harsh line along this outline. By feathering the selection edge, you will obtain a gradual change of tone. From the pull-down menu: Select>Feather, and type the number of pixels to feather. This variable depends upon the overall image size as well as the size of the selection. Usually use 30 for a large selection on a large file size, and 5 or 10 for small selections such as one around portions of an optic nerve.

The Adobe® Photoshop® Tutorial

(continued from page 17)

Now select the pull-down menu: Image>Adjust>Curves. For light/dark adjustments, grab the middle of the straight line and drag it one way or the other to bend it into a curve. Creating a curve with a steeper slope will increase overall contrast. Drag the bottom left corner to the right to increase black density, or drag the upper right corner to the left to increase white density. Adjust areas of tonality in each layer so that the smoothed edges of the original images blend smoothly.

8. To adjust color balance, open Image>Adjust>Curves. Within this control, click on the "Channel" box and select either Red, Green, or Blue. Bend the curve to balance the image-boundary of one level with another. Tonality and color may also be adjusted using the Image>Adjust>Levels command. It is often best to make adjustments in ever-decreasing sizes of complex tonal situations: work on large areas first, then smaller areas; work on gross changes first, then fine tune the image.

9. When you are finished making each of these corrections, compress all the layers into one, or "flatten" the image. In the Layers palette, click the upper-right arrow-box to open the sub-dialogue box and select "flatten image." Or, from the pull-down menu: Layer>Flatten Image. At this point, you may still want to correct color and tone in some problem areas. Do this by using the lasso tool to isolate that area, feather the selection, and make that area balance with its adjacent areas.

Use the Healing Brush Tool, Clone Stamp Tool, and the Dust and Scratches Filter to remove any imperfections.

10. If desired, you can crop the final image into a circle. Click and hold the marquee tool until the marquee options appear, and release on the Elliptical Marquee Tool icon. Draw a circle (holding the shift button while you select) or oval within the boundaries you want to include. Pull down Select>Inverse, then Edit>Fill. Select "black" or a foreground color under the 'Contents' pulldown. Crop the image to size using the cropping tool.

REFERENCES

1. Saine, P, Tyler M. *Ophthalmic Photography: Retinal Photography, Angiography, and Electronic Imaging*. Second edition. Boston: Butterworth-Heinemann. 2002;18, www.TwinChimney.com.

2. Davis MD, Norton EWD, Myers FL. The Airlie Classification of Diabetic Retinopathy. Chapter 2 in: *Symposium on the Treatment of Diabetic Retinopathy*. Goldberg MF and Fine SL. US Department of Health Education and Welfare Public Health Service Publication Number 1890; 7 - 37. 1968.

3. Wong D. *Textbook of Ophthalmic Photography*. Birmingham: Inter-Optics Publications. 1982; 56.

4. Pomerantzeff O, Govignon J. Design of a wide-angle ophthalmo-scope. *Arch Ophthal* 1971;86:420-424.

5. Panoramic Imaging of the Ocular Fundus Carol L. Shields; Miguel Materin; Jerry A. Shields *Arch Ophthalmol*. 2003;121:1603-1607.

6. Deguchi T, Ryutaro O, Noyori K, Kaneko M. "Super-wide field fluorescein angiography with angle magnifying lenses." *J Ophthalmic Photog* 1992;14:49-51.

7. Gilman J. Wide-angle photography of the retinal periphery using the Rodenstock Panfundoscope. *J Ophthalmic Photog* 1989;11:61-63.

8. Clark T, Ozerdem U, Bartsch D, Mach-Hofacre B, Irkee M. A simple non-contact wide angle fundus photography and fluorescein angiography procedure for clinical research. *IOVS* 2000;41:S169.

9. Sachs, J.M. A Curious Mixture of Maps, Dates, and Names. *Mathematics Magazine* v.60, #3, June 1987, pages 151-158.

10. Hackel R. Editor's Letter/About the cover. *J Ophthalmic Photography* 1995;17:53.

11. Mody C, Farr R, Ferguson E. A digital approach to wide field pho-tomontages of the ocular fundus. *Br. J Ophthalmic Photography* 2000;3:12-17.

12. Gosen G. *Early Medical Photography*. Ciba Symposia. 1942. 4;5:1344-1355.

13. Adams A. *The Print*. Boston: New York Graphic Society. 1950; 19.

14. Tyler ME. "Total tonal information in fluorescein angiography". *J Ophthalmic Photography* 1979;2:62-63.

15. Barry CJ, Yogesan K, Constable IJ, Eikelboom RH. "A case of electronic manipulation of medical images?" *J Audiovisual Media in Medicine* 1999;22;1;15-20.

16. Kong CH, Barry CJ. A simple and cheap alternative to slide scanning. *J Ophthalmic Photography* 2003;25:90-91.

17. Blatner D, Fraser B. *Real World Adobe Photoshop 7*. Berkely: Peachpit Press. 2002.

18. Tyler M, Saine P, Bennett T. *Practical Retinal Photography and Digital Imaging Techniques*. Boston: Butterworth Heinemann. 2003, www.TwinChimney.com.