

Review

Ophthalmic imaging today: an ophthalmic photographer's viewpoint – a review

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ABSTRACT

Ophthalmic imaging has changed dramatically since the 1960s with increasingly complex technologies now available. Arguably, the greatest changes have been the development of the digital camera and the speed, processing power and storage of electronic data. Already, ophthalmic practices in many major institutions overseas have paperless medium storage and electronically generated reporting from all equipment that use a computer interface. It is hard to remember the widespread use of photographic film with its attendant costs, or even to remember the days before optical coherence tomography (OCT). These latest technical improvements in ophthalmic imaging are now standard in large Australian institutions and becoming more widespread in smaller private practices. The technicians that operate and maintain this ever-increasing plethora of gadgetry have seen their work practices change from the darkroom to the complexities of data-based imaging and storage. It is a fitting time to examine the contemporary state of ophthalmic imaging and what lies on the horizon as we move towards 2020.

Key words: fluorescein angiography, imaging system, indocyanine green angiography, retinal examination, scanning laser ophthalmoscope.

INTRODUCTION

Ophthalmic imaging has long played an important role in the documentation and diagnosis of ophthalmic diseases. Ocular photography is used to record medical conditions, track disease progression and create illustrations for publication and education. The primary role of ophthalmic imaging however, goes well beyond documentation in its ability to aid in the diagnosis of a broad range of eye conditions.

The history of ophthalmic photography dates back to the late 1800s when Jackman and Webster described a technique for photographing the retina of a living human subject.¹ The next 50 years witnessed a slow advancement in instrumentation and techniques. Photographic results were mostly inadequate owing to slow film speeds, long exposures and inconsistent light sources. In the 1950s, electronic flash and 35 mm cameras were adapted to ophthalmic instruments and modern ophthalmic photography was born.

Ophthalmic imaging can, at times, be either simple or incredibly complex. Ocular tissues can be opaque, translucent or transparent. Enhancement of anatomic features is often achieved through lighting techniques, but sometimes, vital stains, fluorescent dyes, monochromatic light or specialized optical devices or techniques are needed to adequately document subtle pathology.

The following is a brief overview of the techniques being used in ophthalmic imaging today.

EXTERNAL EYE PHOTOGRAPHY

Perhaps the most obvious, but least specialized, type of ophthalmic imaging is termed 'external photography'. Conventional macrophotography equipment and techniques are used to document the external appearance of the eyes and surrounding lid and facial structures. It is commonly used to document lesions of the eye or surrounding tissues, demonstrate facial nerve anomalies and record pre- and post-surgical alignment of the eyes or eyelids.

Digital single-lens-reflex cameras are used to avoid parallax between lens and viewfinder and they offer a variety of compatible lens and electronic flash choices. Magnification for routine external ocular photography ranges from full face up to life size. Dedicated macro lenses are the best choice to provide this range and facilitate repeatable magnification settings. Auxiliary electronic flash units with a variable positioning system provide directional lighting that can be

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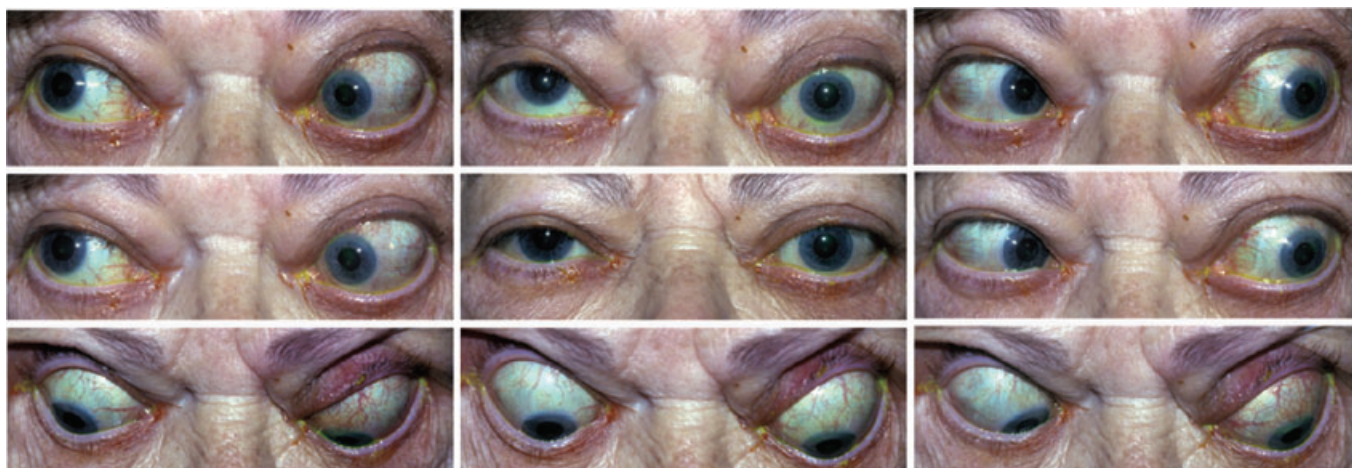


Figure 1. External photograph of the nine positions of gaze documenting thyroid-associated ophthalmopathy. The eye muscles are enlarged pushing the eye forward, preventing the eye moving properly and resulting in double vision.

adjusted tangentially to demonstrate texture and elevation or moved to an axial position to illuminate a cavity, or to accurately render skin colour with even lighting.

It is essential that a standardized series of images with known magnification and lighting are used for the serial follow up of facial and eye conditions so that images remain comparable even when serial sets are taken over extended periods of time.²

Motility photographs are a series of external photographs showing both eyes together in various positions of gaze (Fig. 1). They are used to demonstrate alignment or misalignment of the eyes owing to imbalanced extraocular muscles or other disorders that can obstruct or limit normal eye movement. In addition to still images, these eye movement disorders are sometimes documented with video.

SLIT-LAMP PHOTOGRAPHY

Most high magnification photography of the anterior segment of the eye uses a photo slit-lamp. The photo slit-lamp is a variation of the slit-lamp biomicroscope routinely used in ophthalmology to light and examine structures in the eye at magnifications up to 40 \times .³

Slit-lamp photography offers the best opportunity for imagers to demonstrate their imaging skills and creativity. It is a technically and aesthetically challenging discipline that requires a good understanding of composition, magnification, lighting principles, precise exposure control and understanding of the pathology. Photo slit-lamps use beam splitters to direct image-forming light to a camera mounted on the instrument, or in some cases, two cameras to provide stereo capture. Electronic flash illumination is delivered through the same condensing optics as the tungsten slit illuminator. Magnification at the film plane is adjustable from approximately 0.7 \times up to around 5 \times , depending on the specific instrumentation. The slit beam can be precisely controlled and adjusted from a round or wide rectangular beam down to a very thin slit. A

secondary fill light is often available to add background illumination and adjust lighting ratios.

Lighting techniques fall into two basic categories, direct and indirect. Direct focal illumination can be delivered axially, or tangentially to produce highlights and shadow. Specular reflection can be used to detect surface irregularities in highly reflective structures. A very thin focal beam is often used to create a narrow cross-sectional view or 'optical section' of the normally transparent cornea and lens. Indirect illumination can take on many forms. Iris transillumination, sclerotic scatter and retroillumination of the cornea or lens are lighting techniques that are accomplished by bouncing or scattering light off other anatomical structures such as the iris, retina and sclera (Fig. 2).

Vital stains may be used as an adjunct to slit lighting techniques to enhance visibility of certain ocular surface disorders.⁴⁻⁶ Topical applications of Rose Bengal, lissamine green or fluorescein can be applied to stain areas of missing or devitalized cells in the cornea and conjunctiva (Fig. 3). These dyes are best photographed using diffuse or broad beam, focal illumination. Fluorescein staining can be illuminated with white light to demonstrate yellow staining or with blue light to cause excitation and fluorescence of the dye-stained areas.

GONIO PHOTOGRAPHY

Auxiliary lenses are sometimes used with a photo slit-lamp to photograph the inner structures of the eye that cannot be directly viewed with the slit-lamp.⁷ The most common lens type is the gonio contact lens that utilizes internal mirrors angled at approximately 60° to provide observation of the filtering angle of the anterior chamber (Fig. 4).

SPECULAR MICROSCOPY

Specular microscopy is a variation of slit-lamp photography that utilizes specialized single-purpose instruments to image

Figure 2. Slit-lamp illumination. (a) Slit-lamp photograph with direct, focal illumination of an eye with keratoconus, a conical elongation of the corneal curvature. (b) Specular illumination highlights the 'beaten metal' appearance of the corneal endothelium in a case of Fuchs' corneal dystrophy. (c) Sclerotic scatter, a form of indirect illumination, demonstrates the widespread appearance of granular corneal dystrophy. (d) Thin-beam illumination helps to isolate structures by creating an 'optical section' of transparent tissues in the eye. Here it illustrates a pigmented cyst that has come in contact with the posterior surface of the cornea.

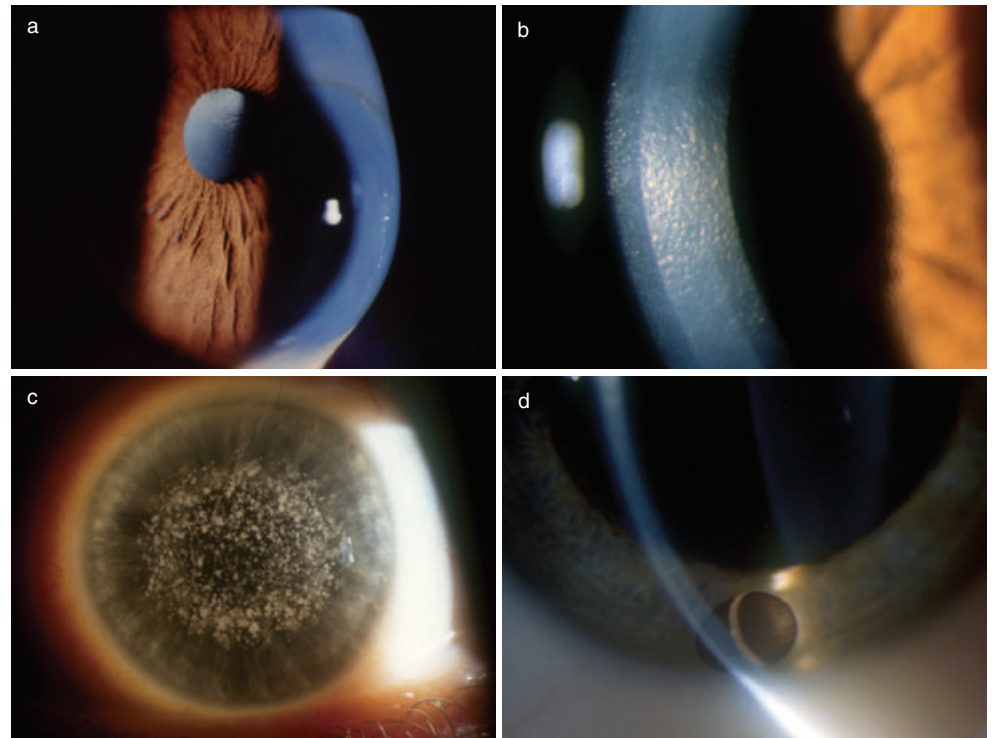
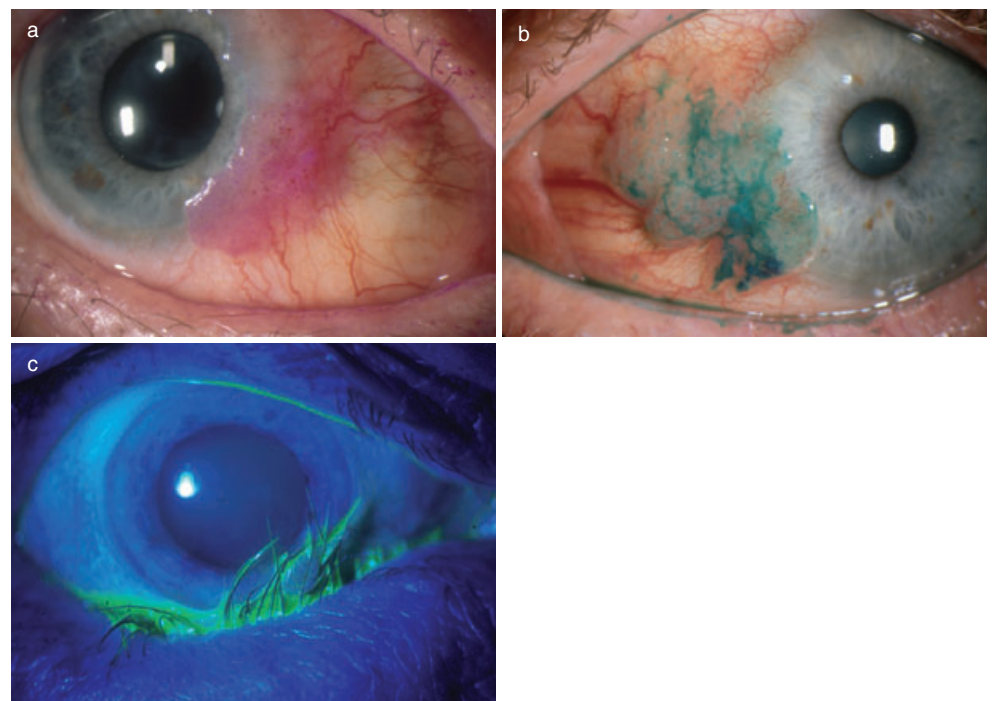


Figure 3. Topical stains. (a) Rose Bengal staining of devitalized areas of a squamous cell lesion. (b) Lissamine green staining of a similar squamous cell neoplasm. (c) Topical fluorescein staining shows the tear-film pattern in a patient with entropion and trichiasis. Diffuse illumination through a blue filter excites fluorescence of the dye.



the endothelium of the cornea.⁸ High magnification and specular reflection are necessary to delineate the cell borders to detect cell density and morphology, which are indicators of corneal health (Fig. 5). Magnifications range from 20× to

200×. Traditionally, specular microscopes required contact with the patients' cornea. The latest instruments utilize non-contact microscopy with semi-automated digital analysis of cell counts and morphology.

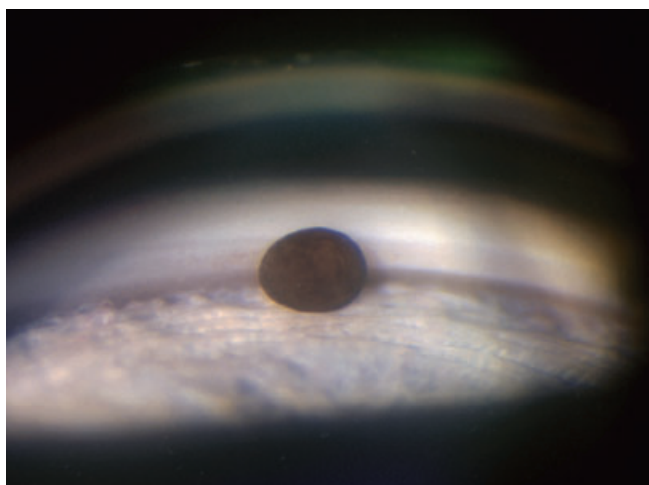


Figure 4. Gonio photograph of a pigmented cyst in the filtering angle of the same eye shown in Figure 2d.

RETINAL PHOTOGRAPHY

The retina represents the single most important subject for ophthalmic photographers (Fig. 6). Retinal imaging presents some interesting challenges. Our goal is to photograph anatomic structures that can be measured in microns, with enough detail to make diagnostic decisions.

Successful retinal imaging relies on the interaction between the optics of the fundus camera with the optics of the eye itself. Fundus cameras utilize an aspheric objective lens design that, when combined with the optics of the subject eye, matches the plane of focus to the curvature of the fundus. Although it is essentially a low-power microscope placed just 2–3 cm from the subject, proper focus is set at or near infinity, because when aimed into the eye, the light path exiting the fundus camera then passes through the refracting optics of the cornea and the natural lens, which are usually focused at distance upon dilation. The focus control of the fundus camera is used to compensate for refractive errors in the subject eye. The light needed to illuminate the fundus is delivered axially. The optical system of the fundus camera projects a ring of light from the internal strobe through the dilated pupil. The ring shape allows a separation of the outgoing and incoming illumination (Gullstrand principle).⁹

Retinal cameras are often described by their optical angle of view. An angle of 30 degrees (30°) is considered the normal angle of view and creates an imaging plane image 2.5 times life size. Fixed-angle cameras usually offer the sharpest optics, but variable-angle cameras provide wide-angle capabilities between 45° and 60°. Wide-angle cameras need to illuminate a broader area of retina, requiring a more widely dilated pupil to accommodate a larger ring of light. Other angle of view options are available on some cameras, notably 20°, or accessory magnifiers can be used to increase the range of magnification available and are particularly used in the serial comparisons of optic discs in the evaluation of glaucoma.

Peripheral fundus photography can be particularly challenging. When the eye is rotated to the desired peripheral field of view, the opening in the pupil appears elliptical, making it difficult to fit the entire illuminating beam within its borders. The off-axis angle also causes the image-forming light rays to pass through a flatter portion of the cornea, which will change focus and cause some distortion.

MONOCHROMATIC RETINAL PHOTOGRAPHY

Monochromatic retinal photography is the practice of imaging the retina with the use of coloured or monochromatic illumination (Fig. 7). In 1925, Vogt described the use of green light to enhance the visual contrast of anatomical details of the fundus.¹⁰ The technique is still commonly used in combination with fundus photography. Monochromatic retinal imaging is based on the use of contrast filters to alter subject tones in monochrome images and the increased scattering of light at shorter wavelengths. By limiting the spectral range of the illuminating source, the visibility of various fundus structures can be enhanced.¹¹

Blue light increases visibility of the anterior retinal layers, which are normally almost transparent in white light. Blue light is absorbed by retinal pigmentation and blood vessels, providing a dark background against which the specular reflections and scattering in the anterior layers of the fundus is enhanced. Scattering in the ocular media can limit the effectiveness of these wavelengths. The retinal nerve fibre layer, the internal limiting membrane, retinal folds, cysts and epiretinal membranes are examples of semi-transparent scattering structures that are enhanced with short wavelength illumination (Fig. 8). Because of excessive scattering at very short wavelengths, blue-green (cyan) filters of 490 nm are often used.

Green light is also absorbed by blood, but is reflected more than blue light by retinal pigmentation and provides excellent contrast and the best overall view of the retina. It enhances the visibility of the retinal vasculature and common findings such as haemorrhages, drusen and exudates (Fig. 9). For this reason, green filter 'red-free' photographs are routinely taken as baseline images in conjunction with fluorescein angiography.

In red light, the retinal pigmentation appears more transparent revealing the choroidal pattern. Overall fundus contrast is greatly reduced with red illumination. Retinal vessels appear lighter and become less obvious at longer wavelengths. The optic nerve appears lighter and almost featureless. Red light is useful for imaging pigmentary disturbances, choroidal ruptures, choroidal naevi and choroidal melanomas (Fig. 10).

STEREO IMAGING

Stereo images enhance diagnostic information by providing a visual sense of depth and realism beyond ordinary two-dimensional photographs. The use of this technique in ophthalmology dates back as far as 1909, but it was not until the

Figure 5. Specular microscopy. (a) High magnification specular micrograph of a normal corneal endothelium. (b) Modern, non-contact specular micrograph with cell analysis that includes cell density (cells/mm², and morphology. Photos: Thomas Link).

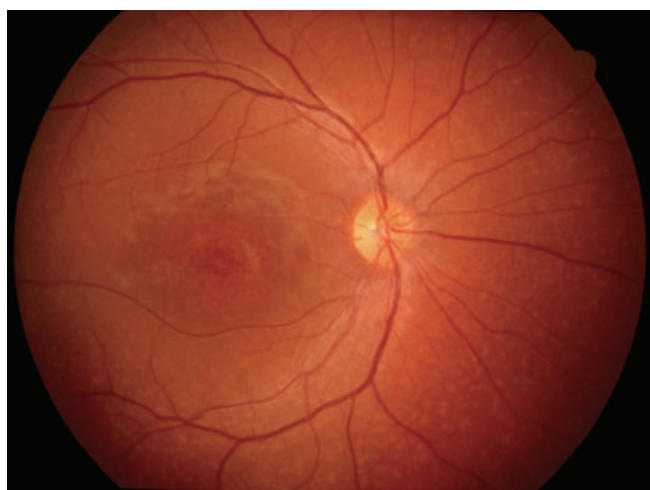
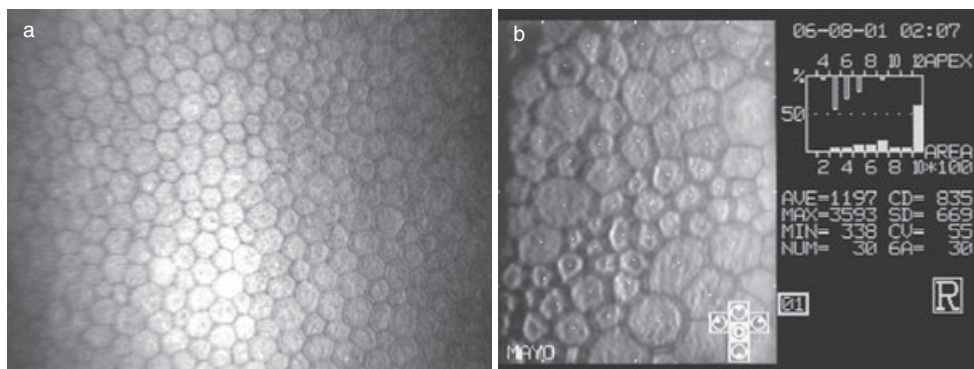


Figure 6. Wide-angle colour fundus photograph showing the optic nerve, retina and choroid of a young patient with Stargardt's disease.

1960s that stereo fundus photography became widely used after Lee Allen described a practical technique for sequential stereo fundus photography.¹²

This technique is a good example of how we can take advantage of the optical interaction between the subject eye and camera. Laterally shifting the fundus camera a few millimetres between sequential photographs causes the illuminating beam of the fundus camera to fall on opposite slopes of the cornea. The resulting cornea-induced parallax creates a hyper-stereoscopic effect that is evident when the sequential pair of photographs are viewed together. Stereo pairs are particularly useful in identifying the anatomic location of pathologic findings in retinal images. Stereo imaging is a standard protocol for many clinical trials investigating treatment of retinal diseases. Critical alignment of digital stereo images can be accomplished through the use of dedicated stereo display software. Controls typically include vertical and horizontal shift, and in some cases incremental rotation. They automatically crop overlapped borders and permit resizing. These programs offer a variety of output formats for stereo viewing including anaglyph, side-by-side, interlaced and 'page-flip' for LCD shutter glasses.

Stereo imaging techniques have also been used for slit-lamp biomicrography and, to a lesser extent, external photography. Unfortunately, the two commercial simultaneous stereo cameras (both images of a stereo pair taken at the same moment in time, Nidek 3Dx, Topcon TRC-SS) are not available as of 2007. There are a variety of optical stereo viewers available for viewing digital images on a computer monitor. All stereo viewing devices are designed to deliver the separate stereo images simultaneously but independently to each eye allowing the brain to fuse the pair and recreate a three-dimensional image.

FLUORESCENCE ANGIOGRAPHY

Ophthalmic photography has at times seemed almost synonymous with fluorescein angiography. For over four decades, ophthalmologists have relied on fluorescein angiography as an important tool in the understanding, diagnosis and treatment of retinal disorders. This diagnostic imaging procedure utilizes a retinal camera or a scanning laser ophthalmoscope to capture rapid-sequence photographs of the retinal vasculature following an intravenous injection of fluorescein sodium.¹³ Fundus cameras are equipped with a matched pair of exciter (465–490 nm) and barrier (520–530 nm) filters (narrow pass interference filters) along with a fast recycling electronic flash tube that allows a capture rate of up to one frame per second. This technique facilitates the *in vivo* study of the retinal circulation (Fig. 11) and is particularly useful in the management of diabetic retinopathy and macular degeneration, two leading causes of blindness. On rare occasions, fluorescein angiography of the iris or other anterior structures may be of value.

SCANNING LASER OPHTHALMOSCOPY

Fluorescein angiography can also be recorded using a confocal scanning laser ophthalmoscope (cSLO) in place of the conventional fundus camera (Fig. 12). The cSLO uses a laser beam of the appropriate excitation wavelength to scan across the fundus in a raster pattern to illuminate successive elements of the retina, point-by-point.¹⁴ The laser can deliver a very narrow wavelength band for more efficient excitation of fluorescence than the flash illumination generated by an elec-

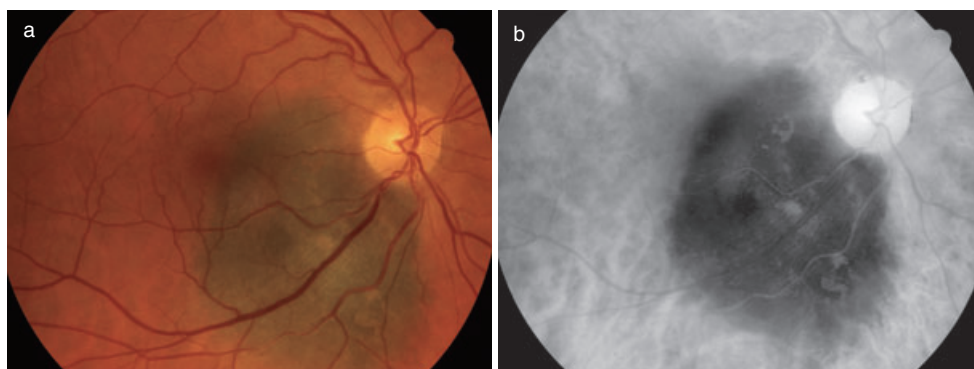


Figure 7. Monochromatic photography. (a) Colour fundus photograph of a suspected choroidal melanoma. (b) Monochromatic photograph of the same fundus taken through a red filter (peak transmission at 615 nm) to enhance and document the borders of the lesion.

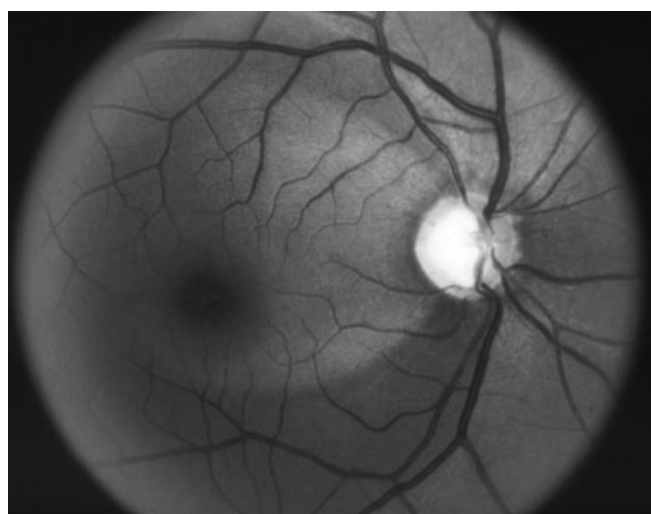


Figure 8. Monochromatic fundus photograph taken with blue-green light (peak transmission at 490 nm). The lack of specular reflections in the dark, wedge-shaped areas identify a loss of retinal nerve fibres from glaucoma.

tronic flash tube. A confocal aperture is positioned in front of the image detector at a focal plane conjugate to the retina, effectively blocking non-image-forming light. The confocal optical system and laser illumination combine to produce high contrast, finely detailed images. The laser scan rate is synchronized at a frame rate compatible with digital video display, providing a continuous high-speed representation of the flow dynamics of the retina and choroid. This can be especially useful when documenting of the very early filling stages in the identification of choiroidal neovascular feeder vessels.

Both 30° and 50° (complete circle rather than clipped top and bottom with fundus cameras) auxiliary lenses are available for the cSLO; the wide-angle lens is primarily used for peripheral imaging in either diabetic retinopathy or venous occlusive disease. In addition, real-time montaging software allows the operator to view a collation of peripheral images on screen as a single ultra-wide angle image. However, the cSLO does not have the capacity to capture colour images of the retina.

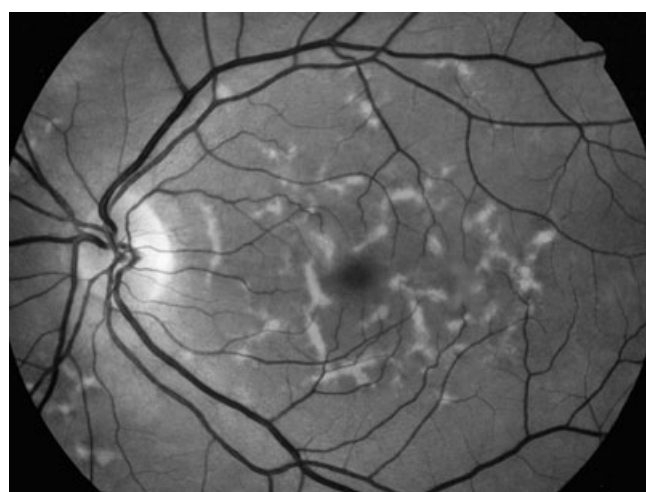


Figure 9. Green light is the most commonly used colour for monochromatic fundus photography. It enhances the contrast between retinal blood vessels and the optic nerve. In this case, a green filter (peak transmission at 560 nm) nicely illustrates the pisciform yellow/white lesions characteristic of Stargardts' disease.

An adapted cSLO (Heidelberg Retinal Tomogram, HRT3) can also be used for comparing optic nerve head parameters in glaucoma.¹⁵ Analysis of the optic disc head topography relative to a confocal reference plane shows small structural changes necessary to detect the progression of glaucoma. Pictures are built up from scanned layers which are represented as two-dimensional topographical or reflectivity pictures by the HRT software. Topographic change analysis compares serial visit data and a probability analysis is compared with a normative database aiding in the identification of glaucomatous progression.

ICG ANGIOGRAPHY

Digital technology facilitates the use of another fluorescent dye, indocyanine green (ICG), for retinal and choroidal angiography (Fig. 13). The choroid is a highly vascular structure found immediately behind the retinal pigment epithelium (RPE), which acts as a physical barrier between the retinal vascular system and the choroidal vascular system.

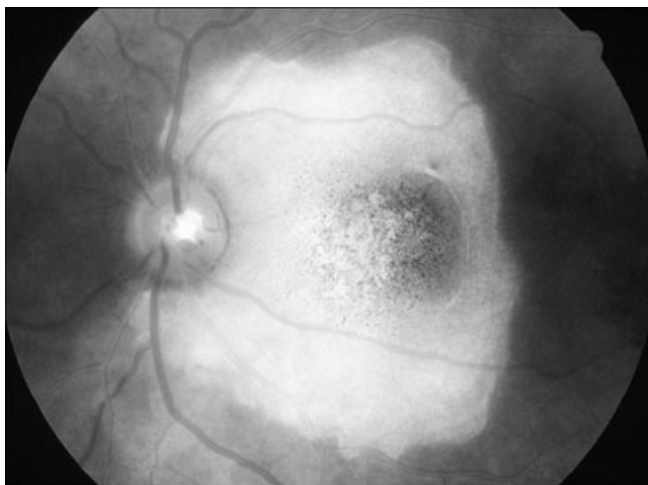


Figure 10. Red light is particularly useful for documenting lesions deep within the retinal tissues or the choroid behind it. Longer wavelengths (peak transmission at 615 nm) partially penetrate the retina pigment epithelium and make it appear more transparent, revealing the scalloped edges of an unusual choroidal osteoma.

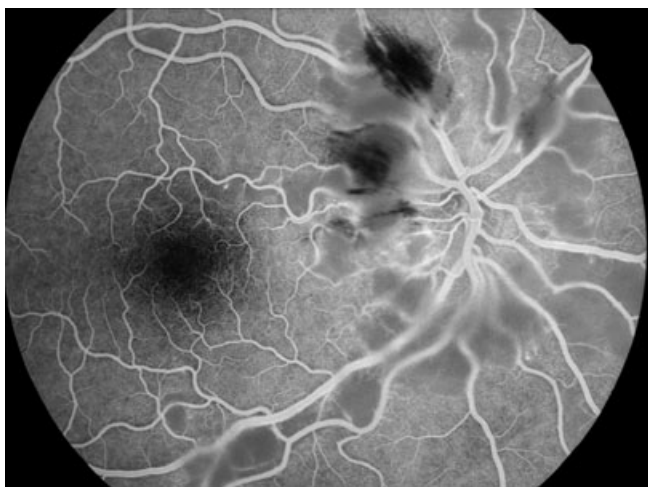


Figure 11. Fluorescein angiogram demonstrating haemorrhages and vascular filling defects in a patient with Purtscher's retinopathy.

The view of the choroid is normally obscured by the RPE, both in clinical appearance and during fluorescein angiography. With peak absorption and emission in the near-infrared range at 805 and 835 nm, respectively, ICG provides greater transmission through the RPE and haemorrhage than the visible wavelengths used in fluorescein angiography (Fig. 13). ICG also binds more completely with blood albumins, so it normally remains within the fenestrated walls of the choriocapillaris, unlike fluorescein, which leaks freely from these vessels.

Indocyanine green choroidal angiography was first performed in humans in 1972, but results were limited by insufficient sensitivity of available infrared films.¹⁶ In the early 1990s, two groups reported improved results with commer-

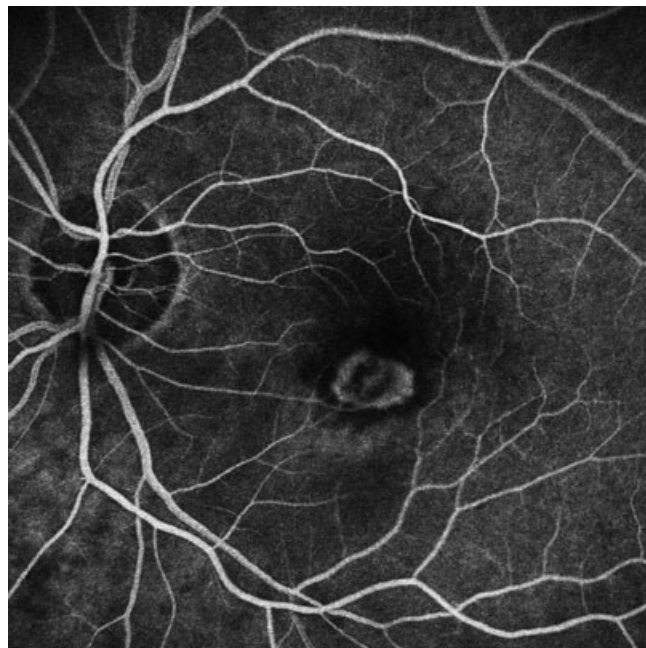


Figure 12. A single frame from a fluorescein angiogram taken with a cSLO showing a choroidal neovascular membrane. The square format of the image is characteristic of cSLO images.

cially available digital angiography systems.^{17,18} The infrared sensitivity of available CCD cameras was combined with new lens coatings that improved infrared transmission for ICG angiography. In the early to mid 1990s, enthusiasm for this procedure exceeded its practical applications.¹⁹ Use of this technique waned by the late 1990s as clinical research had defined a vital, but limited role for ICG angiography as an adjunct to fluorescein angiography.

Today, ICG is used in combination with fluorescein angiography in a limited number of diagnoses where choroidal circulation is effected, such as macular degeneration. The goal in macular degeneration is to identify choroidal feeder vessels that can be treated with a laser to prevent damage to the retina.²⁰ ICG is used in a limited number of diagnoses where choroidal circulation is effected, particularly in polypoidal choroidopathy. ICG is increasingly hard to obtain in Australia with individual specific licensing to perform the procedure now required.

OPTICAL COHERENCE TOMOGRAPHY

Optical coherence tomography is a recent imaging procedure that is useful in the diagnosis of several retinal disorders that have traditionally been imaged with fundus photography or fluorescein angiography.^{21,22} OCT imaging provides direct cross-sectional images of the macula, retinal nerve fibre layer and optic nerve for objective measurement and clinical evaluation in the detection of retinal diseases and glaucoma. It is particularly useful in the detection of macular holes, cystoid macular oedema, subretinal fluid and retinal pigment epithelial detachments (Fig. 14). Its greatest value,

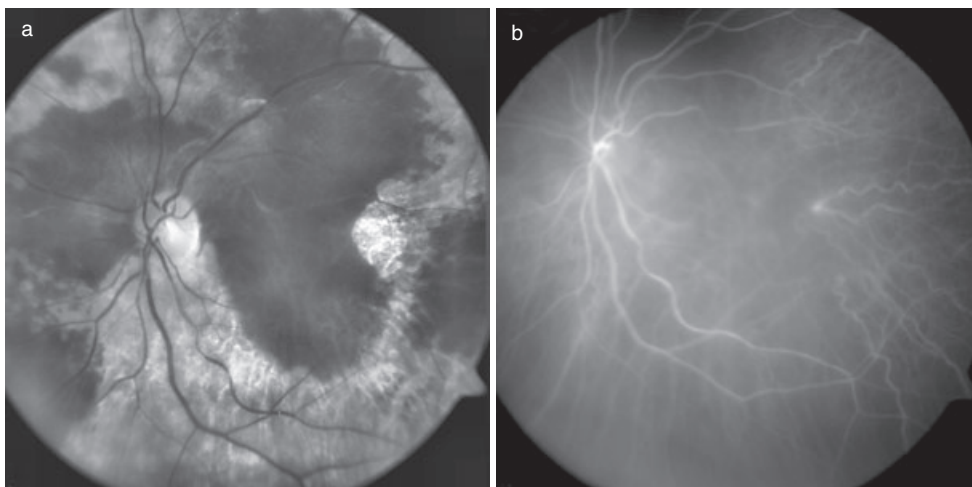


Figure 13. Indocyanine green angiography (ICG). (a) Monochromatic green filter image of an eye with a large subretinal haemorrhage. (b) Infrared imaging penetrates the haemorrhage to reveal the circulation patterns of the retinal and choroidal blood vessels after an intravenous injection of ICG. Photo: Gary Miller.

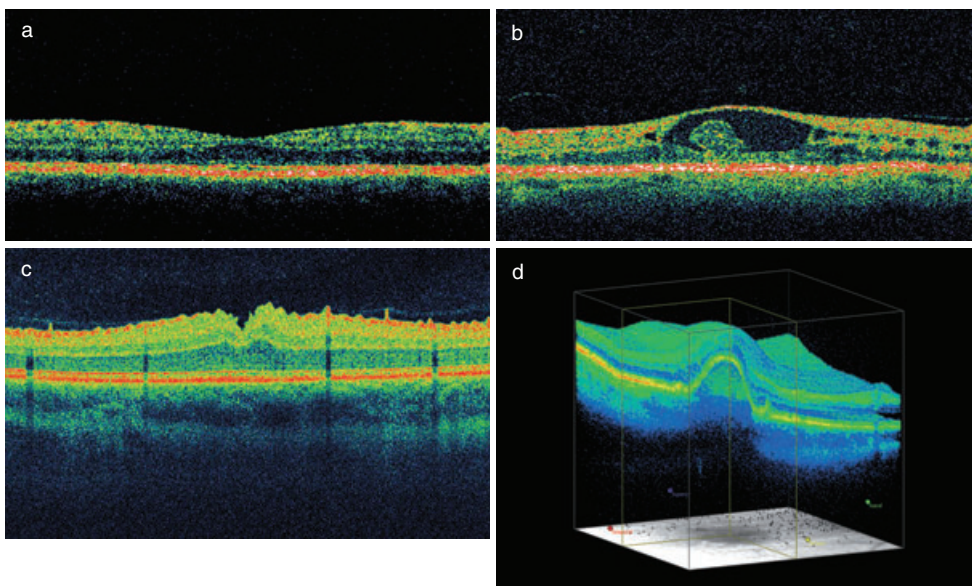


Figure 14. Optical coherence tomography (OCT). (a) A 3 mm line scan provides a cross-sectional view of the normal retinal architecture and foveal depression. (b) A 3 mm line scan of a patient with diabetic retinopathy shows a loss of the normal foveal depression, retinal elevation and fluid-filled cysts. (c) Spectral domain OCT line scan comprised of 4096 A-scans of an epiretinal membrane. Conventional time domain OCT has a maximum resolution of 512 A-scans. (d) The high acquisition speed of SD-OCT offers 3D rendering from a cube scan pattern showing a pigment epithelial detachment in age-related macular degeneration.

however, may lie in the ability to quantify and monitor change in retinal thickness owing to macular oedema from diabetic retinopathy or other causes.

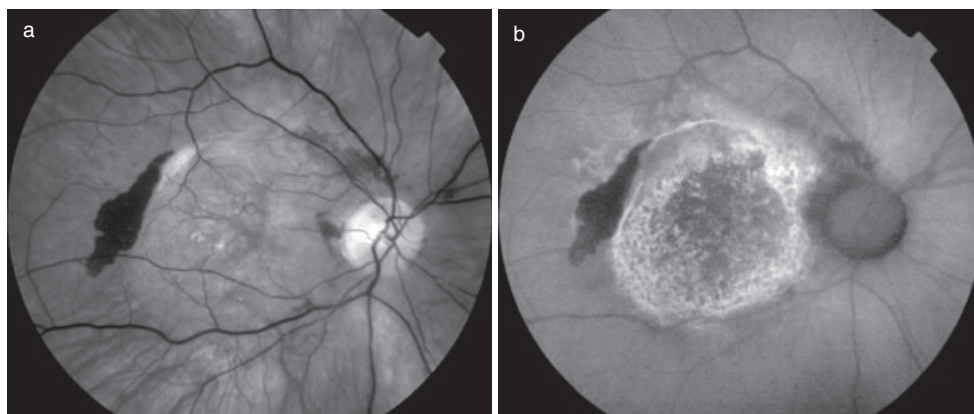
The OCT technology was originally developed at the Massachusetts Institute of Technology in 1991 and is based on the principle of low coherence interferometry.²³ The principle is analogous to ultrasound, except that near-infrared light (820 nm) is used instead of sound. This difference permits resolution of $\leq 10 \mu\text{m}$. A superluminescent diode light is directed at both the eye and a reference mirror at a known spatial location. The time-of-flight delay of light backscattered from different layers of the retina is measured and analysed. Retinal thickness is calculated by processing the cross-sectional images using computer algorithms to detect tissue boundaries by searching for the highest rates of change in reflectivity. Although the technology has been available for over a decade, OCT was mostly used in academic settings or for research applications until the release of the Carl Zeiss Meditec OCT3 in 2002.

New instruments from six manufacturers have recently entered the marketplace using spectral or Fourier domain OCT techniques, and have made significant improvements in both resolution and acquisition speeds, as well as three-dimensional representations of retinal and vitreal structures (Fig. 14c,d). The Heidelberg HRA2 has the ability for fluorescein and ICG angiographies, autofluorescence and spectral domain OCT with the Spectralis module. It remains to be seen whether such a multifunctional device can maintain a high throughput rate for all its many functions available in a busy practice.

FUNDUS AUTOFLUORESCENCE

Fundus autofluorescence is a recently developed non-invasive imaging technique for documenting the presence of lipofuscin in the RPE. Lipofuscin is a fluorescent pigment that accumulates in the RPE as a metabolic by-product as the eye ages. When excited with short wavelength illumination,

Figure 15. Fundus Autofluorescence. (a) Monochromatic green image of a patient with age-related macular degeneration. (b) Fundus autofluorescent imaging (excitation at 580 nm and barrier at 695 nm) non-invasively identifies pigmentary changes and a choroidal neovascular complex.



lipofuscin granules autofluoresce, exhibiting a broad emission spectrum from 500 to 750 nm with peak emission at about 630 nm.²⁴

The original technique used a cSLO with the excitation wavelength set at 488 nm and a barrier filter at 500 nm or 520 nm.²⁵ Several frames are captured with the SLO, then aligned and averaged to reduce noise. Because several frames are required, image quality may be affected by eye movement during capture. More recently, digital fundus camera-based systems have been developed which use high-sensitivity monochrome sensors with an excitation filter at 580 nm and a barrier filter at 695 nm to avoid confounding autofluorescence from the crystalline lens.²⁶ Both systems require significant amounts of light and increased gain settings to achieve adequate exposure and are subject to image noise. Despite the disparity in excitation wavelength and barrier filters between the SLO and fundus camera systems, these two techniques obtain results that are quite similar in appearance.

Autofluorescence imaging has the potential to provide useful information in conditions where the health of the RPE plays a key role. Hyperautofluorescence is a sign of increased lipofuscin accumulation, which may indicate degenerative changes or oxidative injury. Areas of hypoautofluorescence indicate missing or dead RPE cells. Geographic atrophy that appears as a window defect in fluorescein angiography will appear dark in autofluorescent imaging (Fig. 15). A number of investigators are exploring potential applications of this imaging technique in a variety of retinal diseases.²⁷

NON-MYDRIATIC RETINAL CAMERAS AND TELEMEDICINE

Non-mydriatic fundus cameras with digital capture capabilities are often used as screening devices for diabetic retinopathy and glaucoma. Fundus photography can be an effective method of retinopathy screening that is capable of detecting macular oedema and proliferative diabetic retinopathy, the most common causes of vision loss in diabetics. Non-mydriatic fundus cameras are designed with an infrared focusing system that promotes physiologic dilation in a darkened room, making them simple to operate. They can be

placed at remote primary care sites and operated by available clinical personnel such as nurses and medical assistants. Images can then be directed to a centralized reading centre for image grading and treatment recommendations. Imaging with non-mydriatic cameras has been shown to have a high sensitivity and specificity compared with an ophthalmic consultation²⁸ and are becoming an integral tool in delivering ophthalmic care to rural and remote Australia as communication technology becomes more pervasive, particularly in remote Aboriginal communities where the need is high.

Rural and remote diabetic screening programmes in Australia preceded many overseas programmes after recognition of the high prevalence of diabetes in Indigenous communities.²⁹ More streamlined screening programmes are now underway in the USA, UK and more recently, New Zealand. These innovative programmes allow ophthalmologists to make more efficient use of their specialized training to deliver timely treatment to those patients who have been pre-identified through telemedicine screenings. The role of ophthalmic photographers and other ophthalmic technicians has also changed with involvement in training camera operators and in key roles in reading centre workflows.

Conversely, the hand-held Nidek NM200 non-mydriatic camera has been shown to image optic discs well in glaucoma screening but is unable to detect early-stage diabetic retinopathy (intra-retinal microaneurysms) owing to the capture light wavelength,^{30,31} although a hand-held device has been used in prisons in Western Australia as part of an integrated approach to telemedicine consultations with qualified success.³²

OTHER IMAGING MODALITIES IN BRIEF

Various imaging instruments have found acceptance in niche areas. For many years the Kowa RC-2 film camera was adopted as a retinal camera for those difficult imaging tasks such as recording examinations under anaesthesia (Fig. 16). The Kowa Genesis D, two megapixel hand-held digital camera has replaced the film version. The 120° Retcam is now more widespread and frequently used for examinations under anaesthesia, particularly with neonatal imaging; however, there is an appreciable price differential.³³ The

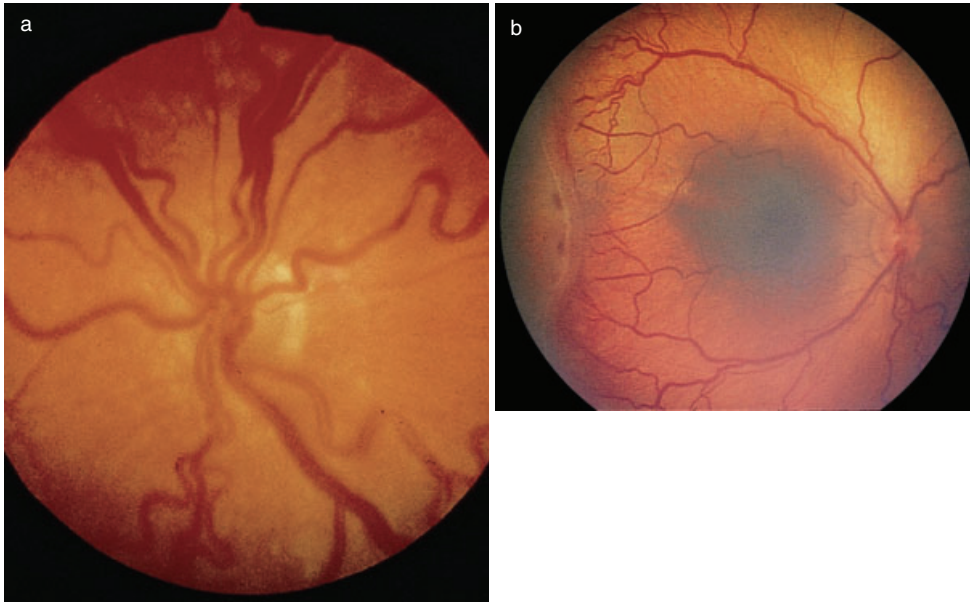


Figure 16. Retinopathy of prematurity: vascular tortuosity involving both veins and arteries, imaged with (a) Kowa RC-2 and (b) Retcam cameras. Photos: Ditte Hess.

Panoret 100 corneal contact camera is capable of a 130° angle of view of the retina using transcleral illumination.³⁴ To date, there are geometric distortions that require manipulation and there is no capacity for fluorescein or ICG angiographies. Easy-to-use wide-angle imaging systems remain a technically difficult and elusive instrument for mainstream usage.

Many other systems now produce computer recreations of captured data. Corneal topography and corneal pachymetry have been at the forefront of data representation, particularly with the advent of laser corneal sculpting to improve refractive errors. The Heidelberg Corneal SL-OCT, Zeiss Visante OCT and the Oculus Pentacam are now entering the market and image the anterior chamber as a three-dimensional cross-sectional structure allowing iris angle analysis, corneal topography, pachymetry and cataract analysis. Perhaps these new modalities will replace high-resolution ultrasound B scans; only time will show which will become the dominant technologies.

SUMMARY

Ophthalmic photographers and ophthalmic technicians now require continuing, high-level, ongoing education to remain current with emerging technologies. Instrument integration into the practice workflow requires a collaboration with Information Technology technicians; however, the ultimate goal of total electronic information remains tantalizingly close in Australia.

There are no dedicated ophthalmic photography training courses in Australia, although the Royal Melbourne Institute of Technology does offer a semester of ophthalmic photography training as part of a Bachelor of Science Degree of Applied Scientific Imaging. Therefore, continuing education is only available at overseas programmes associated with Ophthalmic Conferences. These remain the only available

option to gain a contemporary overview of current and emerging technologies to be incorporated into future clinical practice. With the advent of digital imaging and storage and anti-VEGF treatments, workflows and practices have already changed extensively even though Australian Medicare reimbursement is only available for fluorescein angiography.

Large institutions are moving towards the sole use of electronic records, for example, the USA Veterans Affairs department (VA). Since 1999, the VA's 155 hospitals, 881 clinics, 135 nursing homes and 45 rehabilitation centres have been linked by a universal medical records network that allows any authorized person to look at 5.3 million patients' records (personal communication: Associate Professor Len Goldsmith, Stamford School of Ophthalmology, 2007). In tandem with this new wave of patient electronic information storage, retrieval, transmission and billing, the Health Insurance Portability and Accountability Act in the USA regulates and monitors the security and protection of patient's information, and access is closely monitored. The implementation of a similar system in Australia has yet to be initiated but must be the next logical goal in today's digital world.

Ophthalmic diagnostic imaging enhances the understanding, diagnosis and treatment of a wide variety of ocular disorders. These images are used for decision-making purposes on a daily basis, and in some cases, physicians rely on them as a 'road map' to guide laser therapy. The new technologies of wavefront imaging and microdeformable mirrors are already in the prototype stage imaging *in vivo* cone cells with high-resolution images. These upcoming technologies will require imaging staff to make these purchases cost effective. Integrating this plethora of devices into the clinical workflow will maximize the benefits to patients in terms of clinical outcomes and is the latest challenge in remaining in the forefront of tomorrow's high technology environment.

INFORMATION RESOURCES

The Australian Institute of Medical and Biological Illustration (<http://www.aimbi.org.au>) is the umbrella organization in Australia for medical/ophthalmic photographers.

The Ophthalmic Photographers' Society has produced a journal since 1978. All Journals are available electronically via the web and can be searched by key word, edition or author (<http://www.opsweb.org/Publicat/Journal/JourSrch.html>). The Ophthalmic Photographers' Society can be contacted at: ops@opsweb.org

The Ophthalmic Imaging Association (<http://www.oia.org.uk>).

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