CET 1 point

Imaging the periphery

Christopher Mody describes the evolution of wide field imaging of the retina and how it may be achieved using modern instrumentation (C54676, one distance learning CET point for optometrists)

OCULAR EXAMINATION OPTIONS

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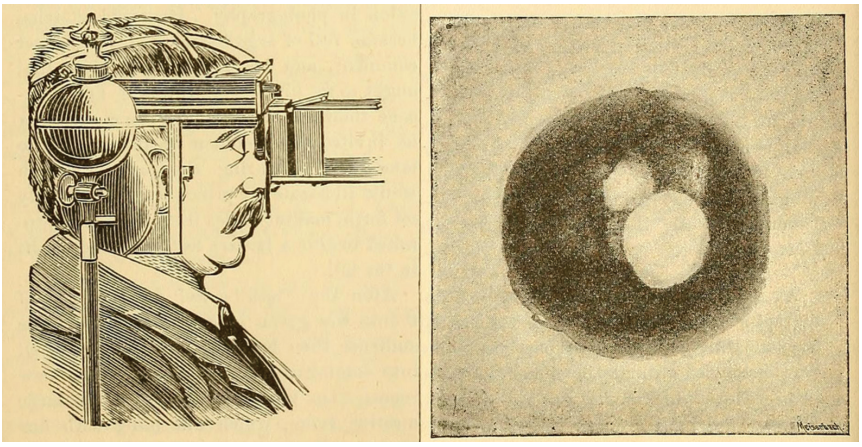
For the ophthalmologist and the optometrist, the requirement to assess the peripheral retina for evidence of pathological change is essential, because conditions such as diabetic retinopathy, retinovascular disease, uveitis and retinal tears often first manifest in the retinal periphery. While examination of the margins of the retina has been available to clinicians since the end of the 19th century, documentation of peripheral retinal change has been challenging and applying diagnostic imaging techniques near impossible. However, recent advances in imaging technology have meant detailed clinical documentation of disease affecting the retinal periphery is now accessible to the clinician as part of a routine assessment strategy.

Since the introduction of the direct ophthalmoscope by Helmholtz in 1851, clinicians have strived to record their clinical findings. The first in-vivo, human retinal photograph is attributed to Dr Jackman and Dr Webster in 1886, who published their findings in the 'Philadelphia Photographer' (figure 1). Using an albo-carbon burner and an ophthalmoscopic mirror to record a photograph of the optic nerve head, the procedure required a 2.5 minute exposure. By modern standards, the image was of poor quality, exhibiting bright corneal reflexes, low contrast and evidence of motion artefact, but nonetheless was a major landmark in the evolution of ophthalmic photography.

The next significant breakthrough was at the start of the 20th century by Dr Frederick Dimmer, who devised a method of accurate, high quality and repeatable fundus photography (figure 2).

FIGURE 1 The first in-vivo human retinal photograph from 1886



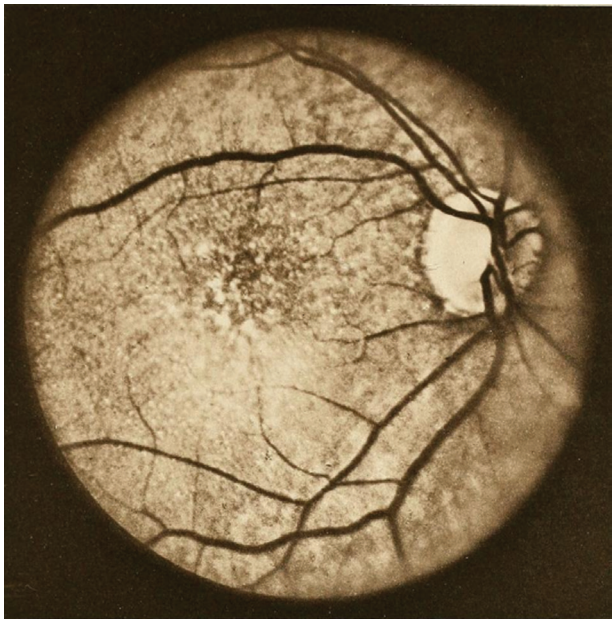


FIGURE 2 Dr Dimmer's accurate and repeatable fundus photography

While the instrumentation used was large and impractical, he was the first ophthalmologist to routinely illustrate clinical papers with photographic fundus recordings and published the first atlas of fundus photography. Only one instrument of Dimmer's design was produced. Further developments in fundus photography came from evolving Helmholtz's principles and it was Nordenson that devised the first practical fundus camera design in 1925, which was commercialised by Carl Zeiss in 1926. The instrument offered a 10° field of view and required a 1.5 second exposure with colour film.

A big limitation of these early instruments was the length of time required to expose film of low sensitivity. The result was that motion artefact in images plagued the pioneers of fundus photography. This limitation was partly addressed when Hansell and Beeson applied the xenon arc flash lamp to a fundus camera in 1953, and from this point forward routine clinical evaluation with fundus photography became practical.

It was the digital imaging revolution that transformed retinal photography. Removing the alchemy of the darkroom from the imaging process meant fundus photography was instantly accessible outside of the specialist eye treatment centres and this resulted in the technique being routinely adopted in optometry

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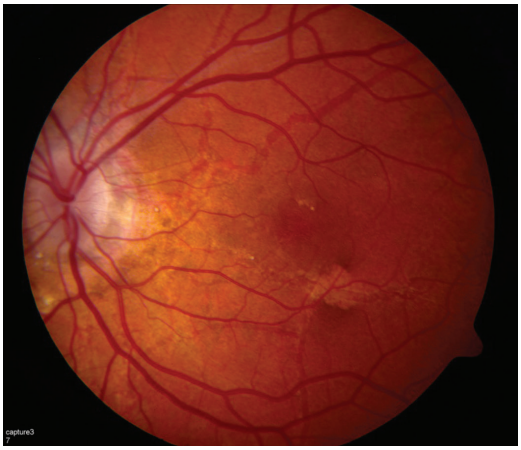

FIGURE 3 Carl Zeiss' FF series fundus camera image

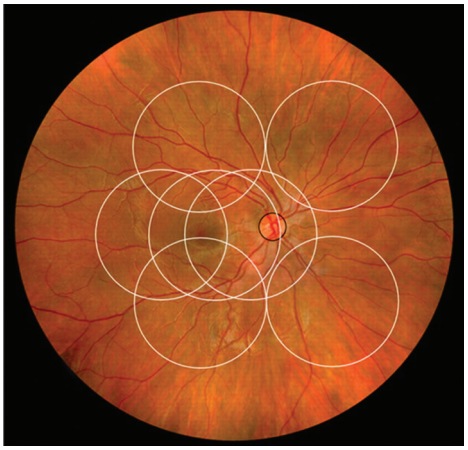

FIGURE 4 ETDRS fundus photography fields

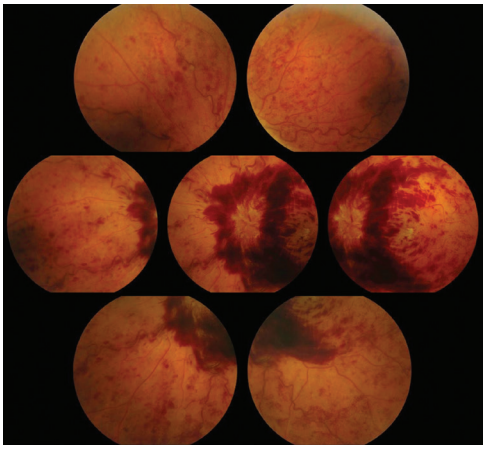

FIGURE 5 Patient with central retinal vein occlusion

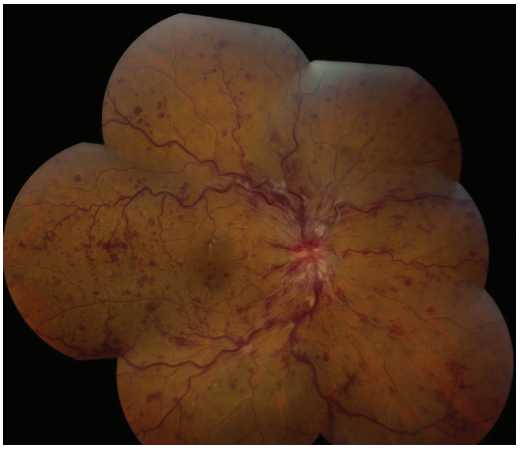

FIGURE 6 Widefield fundus image

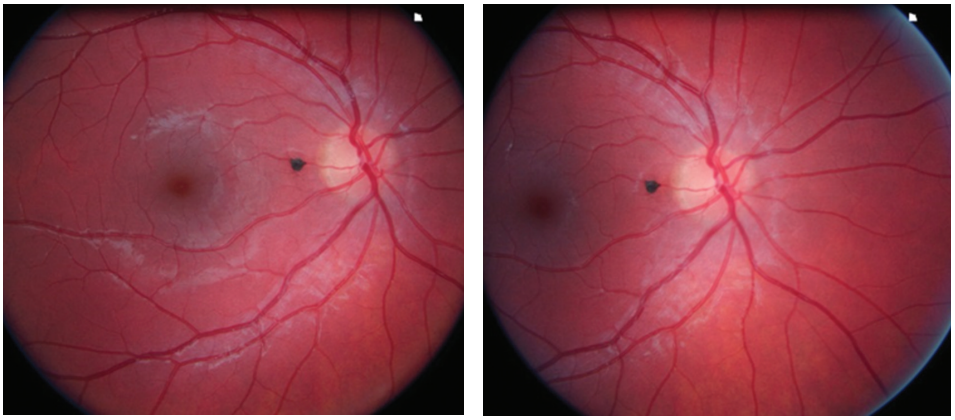

FIGURE 7 45° retinopathy screening fields; disc and macula centred fundus photographs (Canon DGI non-mydriatic fundus camera)

and primary care retinopathy screening programmes.

The standard for mydriatic fundus photography has been a 30° field of view; a magnification that was popularised by Carl Zeiss with their FF series fundus camera. The 30° field of view permits the recording of the optic nerve, macular and vascular arcades within a single image (figure 3).

Historically, imaging a wider distribution of changes within the ocular fundus required taking multiple fundus images, while changing the patient's position of gaze to survey the retinal periphery. ETDRS fundus photography fields have become the standard for clinical trial photography and are adopted by most international grading centres (figure 4). This technique is still used today, and is of particular importance in documenting diseases that affect the retinal vasculature such diabetes or vascular disease (figure 5).

Using montage software, single images from an EDTRS fundus survey can be registered together to produce a widefield fundus image that is approximately 60° x 60° (figure 6). This technique does have drawbacks. Astigmatic aberration introduced during peripheral fundus photography causes distortion and variation of magnification in the images, which is amplified in the final composite image via the image registration process. For routine clinical application this is not significant, but can be an issue if accurate measurement of the images is required.

The desire for clinicians to document a wider field of view during fundus photography led to the development of 45° and 50° instruments, with the 45° field of view being adopted as the standard for retinopathy screening. In diabetic retinopathy screening, two fields are recorded using a non-mydriatic fundus camera (although mydriasis is mandated from retinopathy screening); one field centred on the macula, the other on the optic nerve (figure 7). These two fields permit a sufficient sample of the central and peripheral retina to identify sight threatening changes.

Fundus camera imaging reached a plateau in development during the mid-1980s with the 50° field of view, with a few devices offering up 60°. All these instruments utilised a low power, reflexless microscope and a combination illumination system, comprising of continuous illumination for focus (halogen/tungsten), flash for image exposure (xenon) and a camera sensor to record the image.

In 1980 Webb *et al* described a novel technique for fundus imaging – the flying spot TV ophthalmoscope.[1] This instrument scanned the fundus with laser light, point by point and line by line in a raster pattern, and the reflected light was collected using a video camera sensor as a movie acquisition. This became the first scanning laser ophthalmoscope. The technology significantly reduced the fundus illumination required for recording the image in comparison to traditional fundus photography and permitted dynamic imaging. Commercial scanning laser ophthalmoscopes were developed by Carl Zeiss and Rodenstock during the early 1990s, but due to the high cost were not widely adopted.

It was not until Heidelberg Engineering introduced the HRT that scanning laser ophthalmoscopy was widely deployed as a routine clinical application. The first Heidelberg instruments offered a 20° image field, used a confocal imaging system and →

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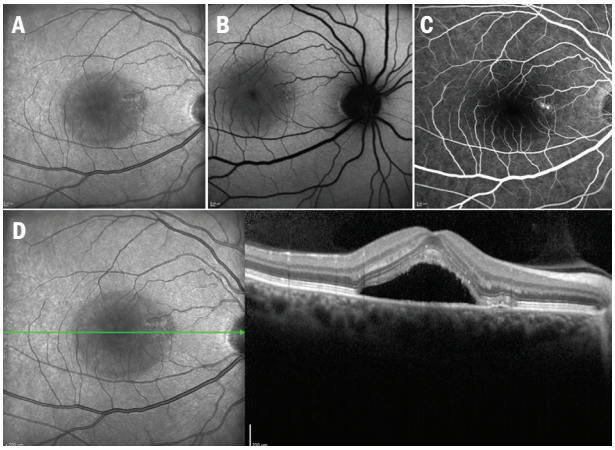

FIGURE 8 A: infrared reflectance. B: BluePeak fundus autofluorescence. C: Fluorescein angiography. D: OCT with simultaneous infrared fundus reflectance (Heidelberg Spectralis).

were designed for optic nerve head tomography in glaucoma assessment. The Heidelberg HRA was subsequently introduced, which uses a confocal scanning laser ophthalmoscope (cSLO) to image the fundus. cSLO imaging enables high contrast, high resolution imaging of the fundus even in the presence of media opacity and through undilated pupils. The Heidelberg instrument has since been adapted to enable a combination of fundus imaging techniques to be applied during a clinical assessment using a single instrument platform, including infrared reflectance, MultiColor, green reflectance (red free), fundus autofluorescence, OCT, fluorescein and ICG angiography (figure 8).

The Staurenghi fundus imaging contact lens yielded the first practical ultra-widefield (140°) angiographic images of the eye (figure 9). However, as it was necessary for the lens to contact the eye to acquire an image, it was not widely adopted in routine clinical practice.

A more popular widefield imaging technique was to use the unique vascular pattern of the retina to register together multiple cSLO images of the patient's eye into a widefield montage (figure 10). cSLO image montages have an advantage in that they exhibit less distortion or variation in magnification than flash photography fundus image montages do. The peripheral retina can be imaged in this way, through adjusting the patients gaze by changing the position of the fixation light and taking multiple images. Alternatively, in some instruments with a panning camera head, it is possible to pan the camera around during image acquisition to record the peripheral retina.

The desire to image an ultra-wide field of view quickly and non-invasively lead to the development and release of an ultra-widefield lens by Heidelberg Engineering, which captures an evenly illuminated, high contrast, wide field of view (102°) in a single shot (figure 11). The lens is simply clipped onto the instrument when it is needed in place of the 30° lens. This technique is most effective, however, when used during angiography assessments due to the inevitable trade-off between image resolution and expanding field of view.

Optos took the scanning laser ophthalmoscope in a different direction and developed a dedicated widefield imaging device. Using an elliptical mirror; a laser is projected to a virtual point where the examined eye is positioned; reflected light is collected at the real projection point and directed to the photodetectors and frame grabber. The first commercial offering was the Optomap P200 series instruments which offered a 200° field of view measured from the centre of the globe and provided pseudo colour, green (532nm) and red reflectance (635nm) and later fundus autofluorescence (FAF) and FA imaging modes. The relatively compact Daytona instrument was designed as a primary care screening instrument and comprises pseudo colour, green and red reflectance and FAF modes permitting visualisation of retinal, choroidal and RPE structure (figure 12). The compromise between image resolution and field of view prevails when using this ultra-widefield imaging technique.

A 55° widefield lens for the Heidelberg instrument subsequently came to market, which provides a compromise between resolution and field of view. The lens enables imaging of the macula, optic nerve head and areas beyond the vascular arcades in a single shot (figure 13). Again, the lens is easily mounted onto the instrument when it is needed and it can be used with a number of imaging modalities including, MultiColor, BluePeak autofluorescence, infrared reflectance and angiography, with simultaneous 16.5mm OCT, providing comprehensive diagnostics in clinical practice. The field of view can be further expanded still by using the montage imaging technique (figure 14).

There is variation in which the field of view is measured by different manufacturers of widefield devices and lenses. The most common method is to measure the field of view from the centre of the pupil. The other method is to measure from the centre of the globe, which will result in an apparently 'larger' angle for the

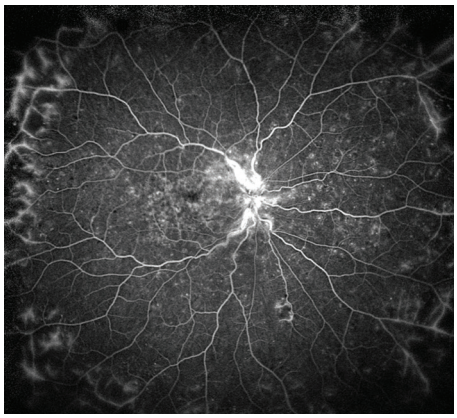

FIGURE 9 140° Fluorescein angiography of central retinal vein occlusion taken using the Staurenghi fundus imaging lens (Heidelberg Spectralis)

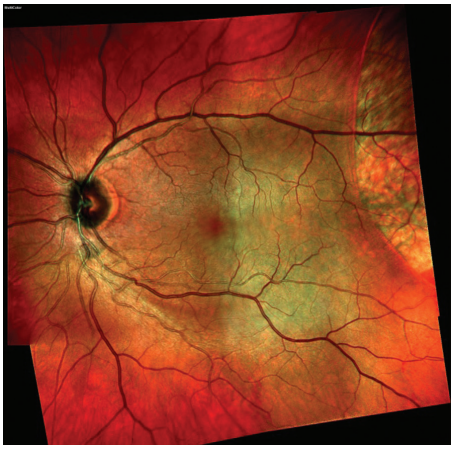

FIGURE 10 Multiple cSLO images of the patient's eye in a widefield montage (Heidelberg Spectralis)

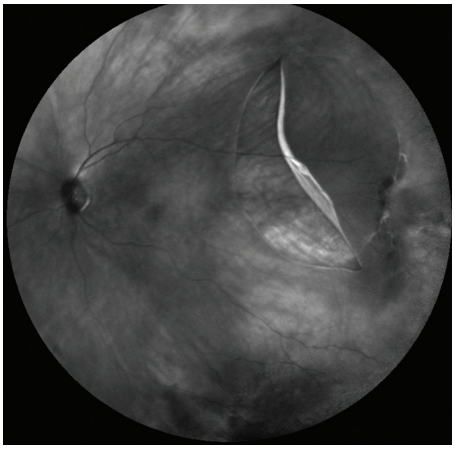

FIGURE 11 Infrared reflectance image taken using Ultra-Widefield Module (Heidelberg Spectralis).

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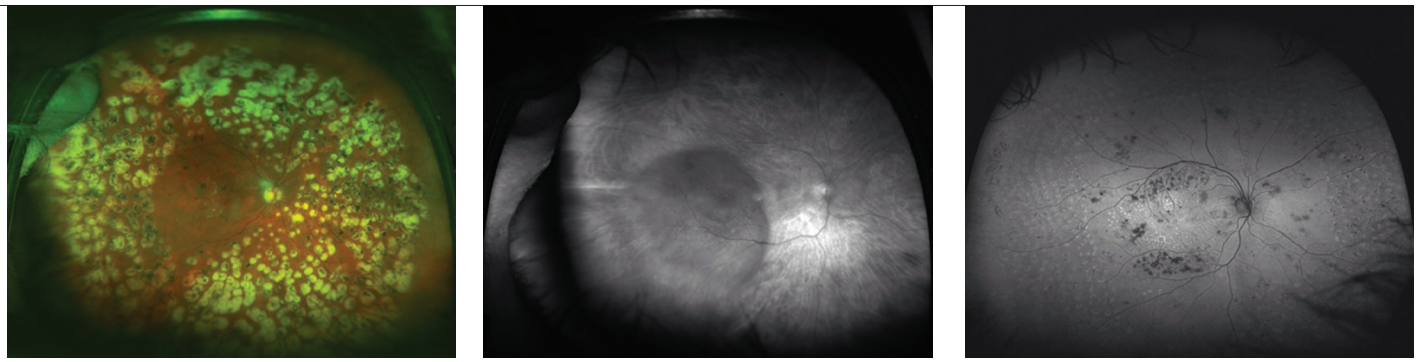

FIGURE 12 Daytona instrument permits visualisation of retinal, choroidal and RPE structure

same area of retina in comparison to the first method (figure 15).

This can make establishing the difference in the field of view between the widefield instruments available a little confusing. Figure 16 illustrates the difference in field of view between the Heidelberg Spectralis Ultra-Widefield Angiography Module (102° fundus field measured from the centre of the pupil) and the Optomap (200° fundus field measured from the centre of the globe). In the image taken using Heidelberg Spectralis two and half vortex veins can be visualised. In the image taken using Optomap, four vortex veins are seen. The image taken using Optomap does suffer from some distortion however, and is less evenly illuminated than the Heidelberg image, so again, there is some trade-off between image quality and field of view/technologies employed.

By applying eye steering during image capture with both devices it is possible to visualise the ora serrata.

The final element of the widefield imaging story is widefield OCT, a combination of widefield fundus imaging and simultaneous OCT (figure 17). At the moment this is limited to a 55° fundus image with a 16mm scan and the primary function is disease identification and monitoring in retinovascular disease, diabetic retinopathy, inflammatory eye disease and vitreoretinal applications.

Widefield imaging provides an opportunity to visualise peripheral retinal structure without the need to subject the patient to a prolonged fundus examination. The clinical utility of widefield fundus imaging is clear; it provides the eye care professional with the opportunity to diagnose and monitor treatment and progression of diseases affecting the retinal periphery using a variety of imaging modalities.

In vitreoretinal applications, it is clear ultra-widefield imaging has a role in identifying peripheral retinal tear and retinal detachment. Figure 18 shows images of a 'horseshoe' tear and prophylactic peripheral laser and figure 11 shows a giant retinal and RPE tear.

Retinal tears require prompt referral and ultra-widefield imaging facilitates examination of the retinal periphery. The post-treatment patient would likely benefit from routine monitoring.

Another application of ultra-widefield imaging is in the diagnosis and monitoring of peripheral choroidal naevus. Pigmented lesions within the eye are surprisingly common, with choroidal naevus affecting about 10 percent of the population. The vast majority of naevus are benign, but monitoring is advised. Widefield imaging can facilitate documentation of these lesions, such as choroidal naevus and congenital hypertrophy of the RPE, which is a much rarer pigmented lesion (figure 19). Both these lesions require referral for confirmation of diagnosis and routine monitoring.

Choroidal and ciliary body melanoma clearly require early diagnosis and rapid treatment, these lesions often present with

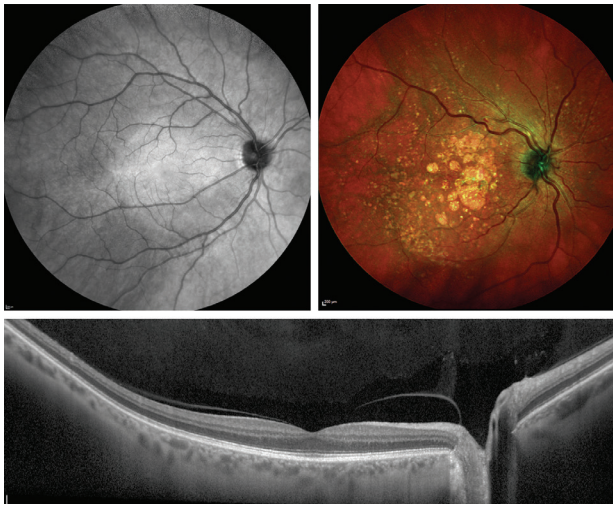

FIGURE 13 Infrared reflectance, MultiColor and OCT images taken using the Widefield Imaging Module (Heidelberg Spectralis)

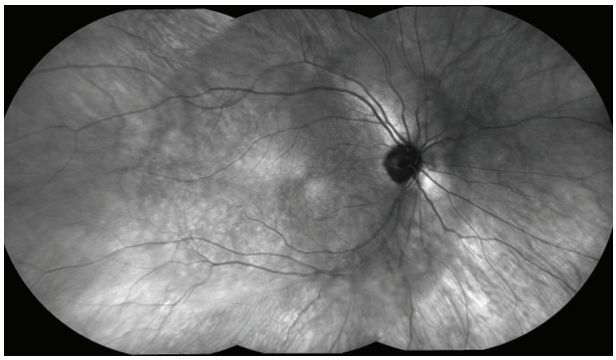

FIGURE 14 55° Infrared reflectance composite (102°x55°) (Heidelberg Spectralis).

retinal detachment. Widefield imaging is clearly advantageous in identifying these changes (figure 20).

Widefield fundus imaging has an application in diabetic retinopathy screening, as it makes it possible to visualise lesions in the retinal periphery associated with retinopathy. However, scanning laser imaging technology has yet to be validated for use in screening programmes. It has a place therefore in early diagnosis and referral, but as yet is not accepted for routine community screening.

It is clear that a myriad of peripheral retinal lesions, ocular diseases and ocular manifestations of systemic disease can be identified with widefield imaging and it may be tempting to adopt this technology for retinal imaging in practice. However, it is important to note that there is a distinct trade-off between field of view and image resolution. An ultra-wide field of view permits →

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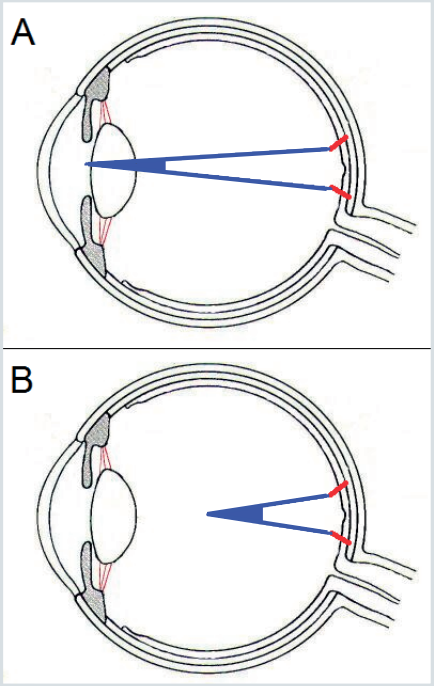

FIGURE 15 Variation in which the field of view is measured by different manufacturers.

a relatively low image resolution in comparison to a 30-55° field of view, as evidenced in figures 10 and 11 of the same eye. In our journey into the periphery, it is important not to forget that the majority of sight threatening disease will be located in the macular region, and it is the macular which is responsible for our high resolution, colour vision. Therefore, while widefield imaging clearly adds value to any healthcare professional involved in fundus assessment, it should act to complement the clinical assessment and examination process and not seek to replace it.

Widefield technologies which can be used as an adjunct to modular imaging platforms with comprehensive diagnostic imaging capabilities are desirable. In this way, widefield imaging gives the eye care professional the ability to improve patient care by providing the tools required to examine the retinal periphery without a protracted examination or compromise on their instruments core imaging capabilities.

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REFERENCES

1 RH Webb, GW Hughes, O Pomerantzeff. Flying Spot TV Ophthalmoscope. *Appl Opt* 1980 Sep;19(17):2991-7.

FIGURE 16 Comparison of Heidelberg Spectralis Ultra-Widefield Module (left) and Optomap fundus image fields (right).

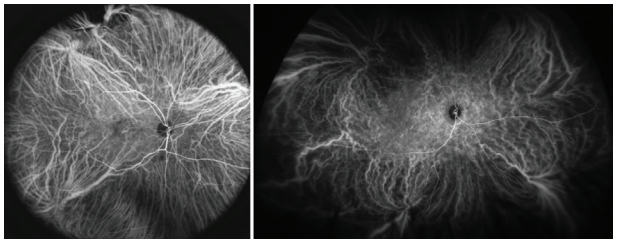

FIGURE 17 Widefield Imaging Module – cystoid macular oedema secondary to macroaneurysm (Heidelberg Spectralis).

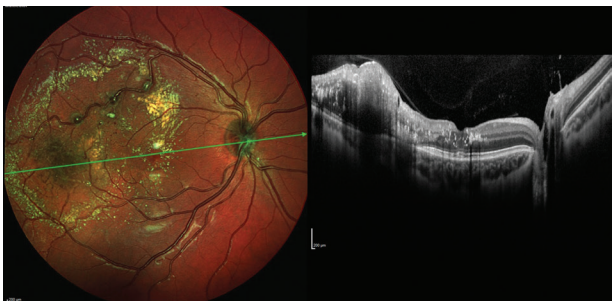

FIGURE 18 A: horseshoe tear and B: prophylactic peripheral laser (Heidelberg Spectralis).

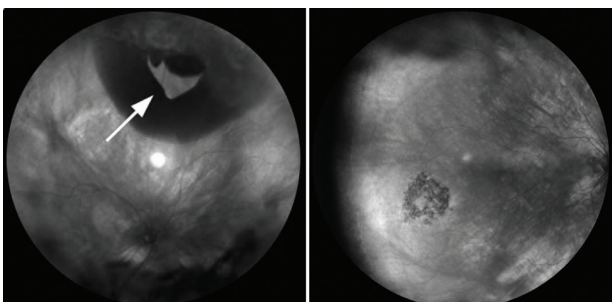

FIGURE 19 Choroidal naevus and congenital hypertrophy of the RPE – a much rarer pigmented lesion

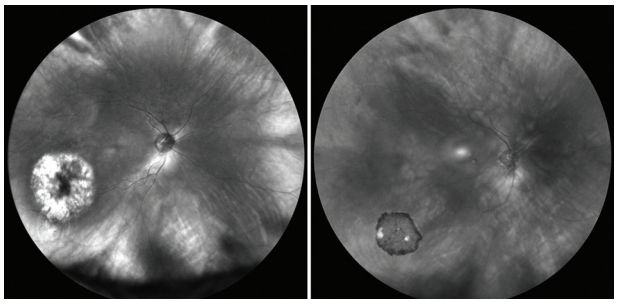

FIGURE 20 Widefield imaging is advantageous in identifying retinal detachment present in choroidal and ciliary body melanoma

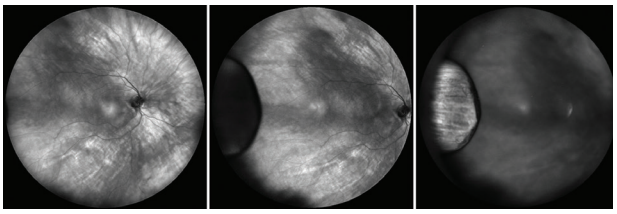

FIGURE 21 MultiColor widefield composite of patient with diabetic retinopathy (Heidelberg Spectralis).