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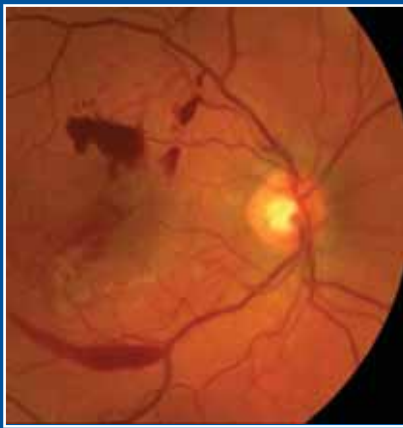
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Module 12 Part 6

COURSE CODE: C-10558/0

Digital imaging and screening for diabetic retinopathy

Christopher C. Hull, PhD



The National Screening Committee has stated that “All people with diabetes aged 12 years and older should be offered screening for sight-threatening diabetic retinopathy using digital photography.”¹ Digital imaging offers several advantages such as archiving, ease of viewing, evidence of progression, quality assurance, patient education and immediate indication of ungradeable images. Knowledge of key aspects of digital imaging technology and performance therefore underpin screening for diabetic retinopathy in the UK. The final article in the ‘Optometric Management of Diabetic Eye Disease’ series aims to discuss the technical aspects of digital imaging related to diabetic screening as well as provide an indication of how computers can be used to automatically screen for sight-threatening retinopathy.

The process of converting an analogue signal, such as light variations in an image, to a digital representation is known as sampling (Figure 1). Sampling has two important parameters: the spatial resolution and how many digital levels or “steps” are used to represent the light. The former is determined by the sensor resolution and the latter relates to the bit-depth of the image. Both will be considered in separate sections below.

In the beginning

Digital imaging can be traced back to the 1930s and Farnsworth’s “image dissector” and Zworokin’s “iconoscope.”² The evolution of digital imaging since then has been intrinsically coupled with that of the digital computer. The modern digital computer dates back to the 1940s when important parallel work was carried out in Germany, the United Kingdom and the United States although only the latter was widely reported because of secrecy. Since then, developments and

miniaturisation have been rapid; it is likely that you have more computing power in your mobile phone than a large desktop computer from 25 years ago. The combination of the ability to record images digitally and modern computers has led to exciting developments in digital image processing, an aspect relevant to diabetic screening.

Steps in the digital imaging process for diabetic screening

Figure 2 shows the steps in the imaging process. Emphasis is placed on image sensor resolution yet this misses several other potentially important parts of the process that could limit resolution and the ability to screen for significant pathology. The steps listed in Figure 2 will be explored in the following sub-sections:

Optics of the Examined Eye

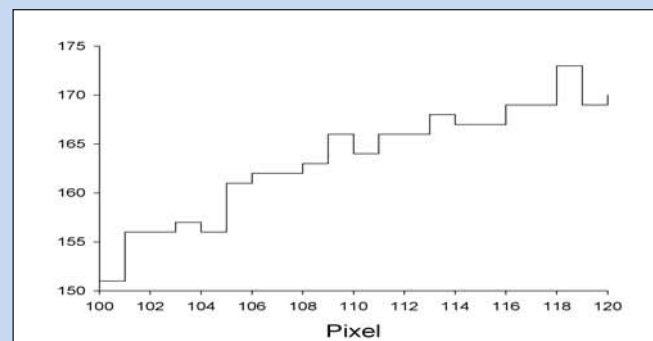
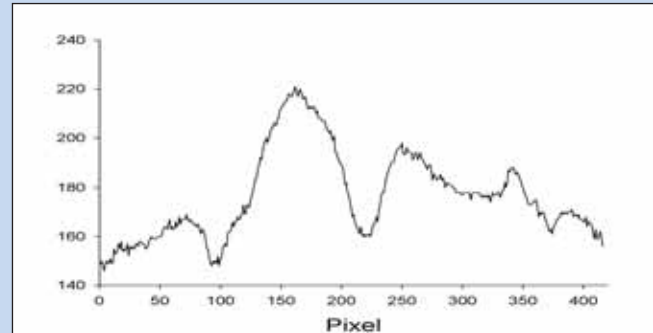
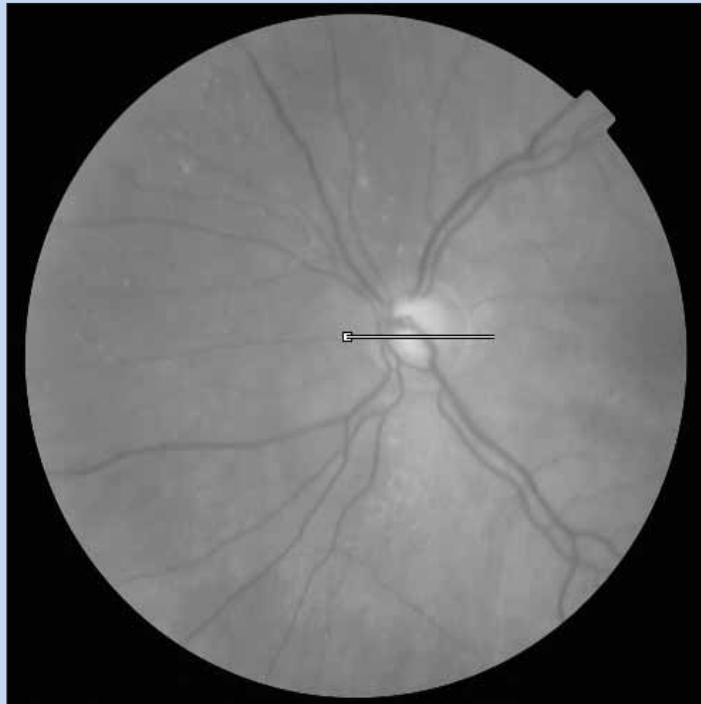
We assume that sufficient light has

been directed on to the fundus and that it is reflected/scattered back out of the eye. The quality of optical systems is commonly measured using the modulation transfer function (MTF); the change in image contrast with increasing spatial frequency for a 100% contrast sinusoidal grating object. The smallest clinically visible microaneurysm is generally considered to be $30\mu\text{m}$, although the size may vary from $12\mu\text{m}$ to over $100\mu\text{m}$. Therefore, the optics must give sufficient contrast at 5 cycles/degree if the microaneurysm is to be resolved (assuming the second nodal point of the eye lies 17mm from the retina). Although measurements of MTF in normal eyes vary, there is clear indication that this requirement is easily met⁴. In addition, 5 cycles/degree corresponds to an acuity of 6/36, a level not generally encountered in normal, corrected eyes. The exception would be eyes with abnormally high levels of aberration and/or media opacity or disease.

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➔ **Figure 1**

Fundus image showing a line profile across the optic disc of pixel intensity (graph top right) and an expanded graph showing spatial and intensity sampling (bottom right)

Consequently, the optics of the eye being examined will rarely limit the ability to screen for diabetic retinopathy unless media opacity or significant corneal irregularity is present.

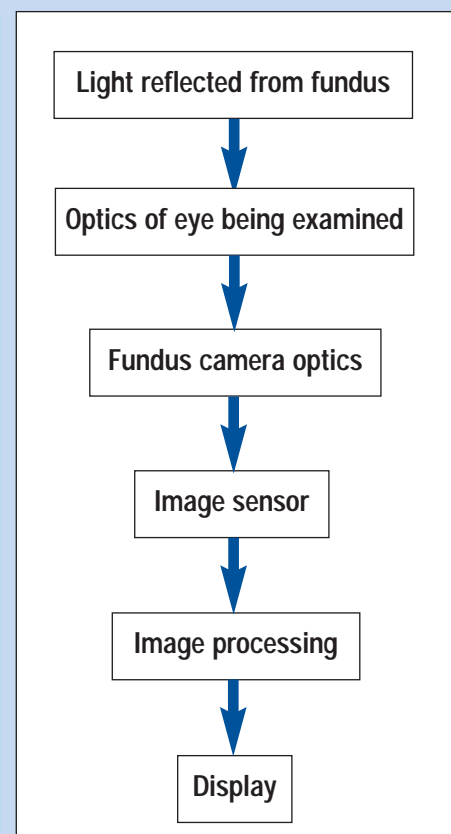
Fundus camera optics

It is possible to make an estimate of the quality of the fundus camera optics to derive a 'ball park' figure that can be compared with the resolution of the image sensor. If we assume an f-number for the fundus camera of f/5.7, then this would produce a diffraction-limited spatial frequency cut-off of 316 cycles/mm for a wavelength of 555 nm. One of the latest digital single lens reflex cameras, the Nikon D3x, has a 24.3Mp (24.3 x 10⁶ pixels) sensor with 6,048 pixels across the 35.9mm width of the sensor. This gives just over 168 cycles/mm resolution, a factor of two less than the assumed fundus camera optics. It is highly unlikely that the fundus camera optics will be a limiting factor and experience of many users and different fundus cameras has not indicated the contrary.

Imaging sensors

At the heart of a digital imaging system is an image sensor that can turn analogue variations in light level into digital information. Modern digital image sensors rely on the ability to fabricate and connect many transistors on a single silicon chip called an integrated circuit. This technology is used to build image sensors as well as other integrated electronic components, such as the microprocessor. However, the basic requirement for an image sensor is very simple; convert incoming photons into electric charge that can be determined at points across an image.

There are two main technologies for digital image sensors: (i) charge coupled device (CCD) and (ii) complementary metal oxide semiconductor (CMOS). CCD image sensors were developed from computer shift register memories and the first solid state camera based on a CCD sensor was developed by AT&T Bell Labs in the USA in 1969⁵. A CCD image sensor consists of a regular array of photodetectors which are



➔ **Figure 2**

Main steps in digital fundus imaging

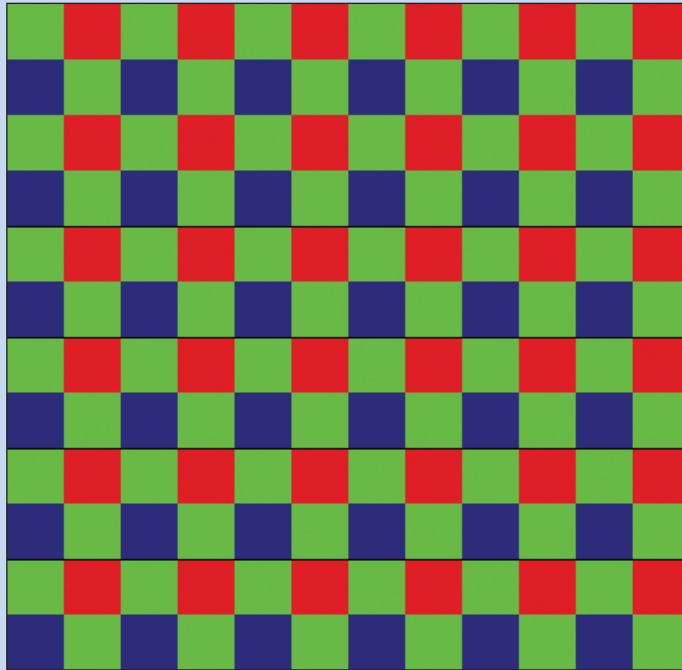


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 ➔ **Figure 3**

Bayer pattern used in the majority of colour filter array image sensors

essentially capacitors that store the electrons generated when light falls on them. Each one of these detectors is referred to as a pixel, a contraction of picture element. The electronic charge, which is proportional to the light falling on the pixel is "read out" into additional circuits using a shift register. A shift register transfers the charge to the neighbouring pixel and eventually on to a 'conveyor belt' that takes the charge to the amplifying and sampling electronics. It is akin to passing buckets of water down a human chain. This process is known as charge coupling. The consequences of the design of CCDs, including the shift register read out are:

1. A high density of pixels leading to good image quality since minimal additional circuitry is needed at the site of the pixel.
2. The power consumption is relatively high.
3. Sequential read-out of each pixel – time taken.
4. Off-board electronics – not fully integrated.
5. Good uniformity since all signals go through the same electronics so more uniform.
6. Leakage of charge from one pixel to

the next – 'blooming'.

7. Good dynamic range.

CMOS image sensors have been developed from the manufacture of logic and memory chips. It has only been since the 1990s that the techniques were sufficiently fine to allow production of image sensors that could challenge CCDs. In a CMOS sensor, each pixel has its own associated electronics, (amplifiers, digital converters) fabricated on the chip next to it. There is no charge coupling and no shift register; the pixels can all be read out in parallel. This architecture has the following advantages:

1. It is faster – parallel read out.
2. Less of the sensor area is devoted to light sensitive detectors – lower image quality.
3. Lower power consumption.
4. Compact "camera on chip" design suitable for applications such as camera phones, web cams etc.
5. No charge leakage particularly if pixel saturated.

For low to moderate cost applications, there is little to separate the technologies and both are adequate for digital photography when screening for diabetic retinopathy. More

technical information can be found in the articles by Litwiller^{6,7}.

Colour image sensors

There are three main methods for generating colour images with digital image sensors: (i) coloured filter arrays (CFAs), (ii) three separate image sensors for red, green and blue channels and (iii) temporal multiplexing using a spinning filter disc. Most low to moderate quality sensors use CFAs. A common pattern for the filters is known as a Bayer pattern where each group of four pixels has two green, one blue and one red sensitive pixel (Figure 3). This arrangement is in part because the sensitivity of the human eye peaks at green wavelengths (555nm).

A colour can be assigned to each pixel in a process known as demosaicing since it removes the mosaic pattern of the CFA. The need for demosaicing becomes obvious if we consider imaging a plain red background; if this produces a response from only the red pixels then there will be a large number of gaps in the image, an obviously undesirable feature. A colour is ascribed to a pixel using information from its neighbours (interpolation) or from assumptions about the colour variation for local groups of pixels in the image (spatial/spectral correlation). The aim is to reproduce the colour in the original image without introducing any colour artefacts. Fundus images contain a limited range of colours hence it is even less likely that colour artefacts will appear in the image that could potentially affect clinical decisions.

Image sensor resolution

Initial estimates of the pixel resolution needed to screen for diabetic retinopathy were based on the smallest clinically visible microaneurysm estimated to be 30µm. For a feature of this size to be unambiguously resolved, the image of the microaneurysm must fall on at least two pixels i.e. each pixel corresponds to 15µm on the retina. For a nominal 45° field and assuming that the nodal point lies 17mm from the retina, this corresponds to an arc length of 13.4mm. This must be imaged by $13.4 \div 0.015 = 890$ pixels of size 15µm. Cameras rarely use the entire sensor so



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the original resolution requirement was stated as 1,365x1,000 pixels by the National Screening Committee. This is a 1.4Mp sensor; a very modest requirement these days and exceeded on most camera phones. The current resolution requirement is stated as 20 pixels/degree since it refers to a circular region common in fundus images.

Sampling and bit-depth

There are two major types of image files: vector graphics and bit-mapped. Vector graphics files are most commonly used in drawing/illustration packages and for CAD (computer-aided design). They mathematically record the shapes in the image which allows more faithful rendering particularly when the image is zoomed. Most images of general objects taken with digital cameras will produce bit-mapped image files where each pixel represents light levels using fixed steps. Therefore, the spatial sampling or resolution of a digital bit-mapped image is set by the number of pixels across the image. The number of steps is known as the bit-depth of the image. It is possible to reduce the bit-depth and Figure 4 illustrates this effect. In a colour image sensor, each pixel records a level for red, green or blue on a scale of 0 to 255. A colour is ascribed to each pixel by combining the 256 levels of red, green and blue leading to the ability to have over 16 million different colours ($256 \times 256 \times 256 = 16,777,216$). It is possible to get 12-bit and 14-bit sensors but 8-bit is perfectly adequate for diabetic screening.

Image file size

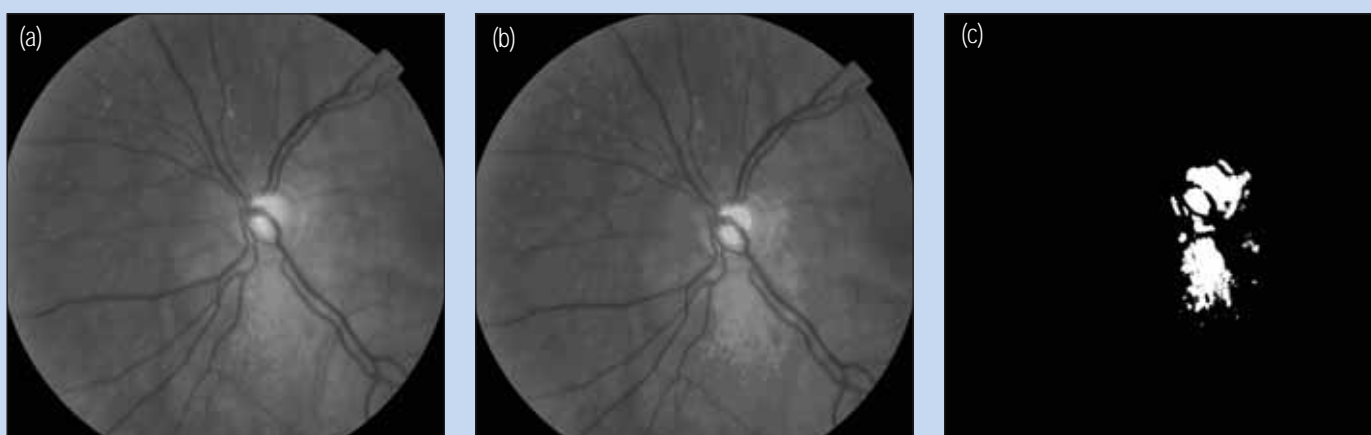
Reducing file size is usually necessary for ease of storage and file handling. To give an example of the scale of the problem, most diabetic screening examinations produce four to six images. For an 8Mp sensor, that would require 144Mb of storage per patient if the files were stored as raw data. Optometrists must complete at least 500 screening episodes per year with a recommendation for 1,500. The recommended number of screenings would produce 216Gb of data. This then needs to be scaled for larger eye departments along with archiving this amount of data and backing it up to a central server. Reducing file size is therefore necessary.

There are three major ways in which file size can be reduced: (i) downsampling, (ii) compression or (iii) a combination of the two. Downsampling reduces the pixel count in the image. It can be carried out within image processing software and a number of image handling packages. We have already shown that a sensor resolution of greater than 2Mp exceeds the screening requirements even allowing for some redundancy. An 8Mp sensor could be re-sampled to reduce the pixel count to 2Mp. There are various ways of achieving this: for nearest neighbour re-sampling, the new pixel grid is effectively overlaid on the original image and the value of the nearest pixel in the original image assigned to

the new pixel. This is a fairly crude technique and it leads to jaggedness and loss of some of the original pixel values. The preferred method of downsampling is bi-cubic interpolation which produces new pixel values, based on interpolation from surrounding pixels, reducing image artefacts and producing a smoother image.

Alternatively, compression can be used to reduce the file size in either a lossless or a lossy way. Lossless algorithms look for redundancy in the images, information that can be coded in a more efficient way. For example, the black corners of a circular fundus image typically contain pixels of the same value and this can be coded perhaps by recording a sequence as 28 pixels of 0 intensity rather than 28 individual instances of 0. This simple approach is known as run length encoding⁸.

The important point to note is that lossless compression algorithms allow the original image data to be retrieved. The most common image file types that use lossless compression are TIFF (tagged image file format), BMP (bitmap) and GIF (graphics interchange format). The latter is likely to cause some confusion since the file sizes are often small and GIF is the default image format for use on the web. GIF only allows 256 colours and hence it is not strictly a lossless format since the original image colours cannot be reconstructed from the file data. The

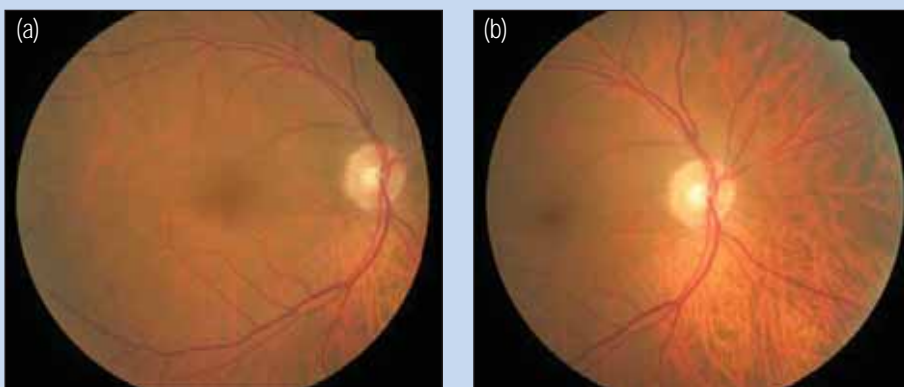


➔ **Figure 4**

(a-c) Fundus image showing the effect of bit-depth: (a) 8-bit (256 levels), (b) 4-bit (16 levels) and (c) 2-bit (2 levels)



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➔ Figure 5

Examples of good quality macula (a) and disc (b) images (see text for details - with kind permission from the English National Diabetic Retinopathy Screening Programme)

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original recommendation of the National Screening Committee was that TIFF files should be used for fundus images when screening for diabetic retinopathy but this has changed.

Lossy image file formats lose information and the original image data cannot be recovered from the data stored. However, if this is achieved without loss of visibly significant information, the file sizes can be much smaller. The most common image file type that uses lossy compression is JPEG. JPEG stands for the Joint Photographic Experts Group, a group set up in 1986 that produced the first JPEG standard in 1992. There are three practical points of note⁹:

1. JPEG was designed to make minimal visible difference to photographic images, ie those that have much smoother gradations in colour and tone. It does not work well on images where there is sharp contrast.
2. Part of the JPEG algorithm works on blocks of usually 8x8 pixels. The edges of these blocks can become visible.
3. Successive decompression when the image is opened and subsequent compression when it is saved will cause a progressive reduction in image quality. This is because the decompressed image contains artefacts that are compressed differently to the original.

JPEG is very effective and the compression ratio can be altered so that you can control the trade-off between image quality and file size. The key factor is the application the images are

used for. The current statement on image compression for diabetic screening is that there should be no loss of clinically significant information. However, it should be noted that many cameras already use compression and produce a compressed (typically JPEG) image for grading. In this case, further compression should be avoided¹.

Compression settings of 12:1 on JPEG are considered acceptable when screening for diabetic retinopathy whereas 20:1 is almost certainly not. As a guide, images over 2.5Mb in size are unlikely to offer any advantage whereas those below 400kB contain insufficient information for screening¹ although no evidence for these claims is given. In Scotland, 2Mb is the maximum image size with 1.5Mb recommended to help with bandwidth constraints. The file sizes can be reduced by downsampling, compression or a combination of the two. Some of the more recent work in this area has looked at just noticeable differences in compressed and uncompressed images once they have been "viewed" by a standard spatial observer (SSO). This is a computer model where the two-dimensional contrast sensitivity function has been modelled for the SSO. The two images, once processed by the SSO, can then be subtracted to see the differences. Using this approach, Helen Li and colleagues at the University of Texas have found that compression ratios as high as 37:1

do not produce just noticeable differences. A new JPEG standard, JPEG 2000, which uses wavelet compression to produce a smoother image (it also has a lossless option), can achieve even greater compression ratios. It is clear that more research on downsampling and compression is needed and the National Screening Committee supports this view.

Display requirements

At some point an image needs to be displayed. Traditionally, this was by printing a negative onto photographic paper, projecting a transparency or taking a Polaroid. Digital images are initially displayed using display screens of which there are two main types: CRTs and flat panel displays. CRTs comprise a cathode producing electrons that are accelerated by an electric field before striking a phosphor. The phosphor emits light and the electron beam is raster scanned across the phosphor to create the image. In recent years, flat panel displays have become increasingly common due to their size and lower power consumption. There are a number of different display technologies that can be used in flat panels but the most common for small to medium size is liquid crystal displays (LCDs). These displays are still inferior to CRTs and have a lower contrast ratio (the black isn't as black as on a CRT), smaller range of colours, are less robust and have a limited viewing angle. All of these limitations are of little relevance to diabetic screening. The key feature of flat panel displays is that they cannot change their screen resolution to match the image being displayed. The screen resolution is fixed unlike for a CRT. As a result, if the image doesn't match the screen pixels then interpolation has to be used possibly resulting in image artefacts. Consequently, the National Screening Committee has recommended that a minimum of a 17" display be used (preferably 19") with a resolution of at least 1,600x1,200. This matches the image resolution requirement of 20 pixels/degree provided no more than 33% of the screen vertically and 45% horizontally is occupied by



menu bars and window frames within the software. Importantly, it is a requirement that flat panel displays are used at their native resolution with care taken over settings for brightness, contrast and colour to maximise the appearance of significant pathology.

Image quality

The National Screening Committee (applied in England, Wales and Northern Ireland) has specified the requirements for good image quality¹: photographers should capture two nominal 45° fields per eye (1 x fovea centred, 1 x disc centred). For the macular image, vessels must be visible across 90% of the image, the centre of the fovea must be less than 1 disc diameter (DD) from the centre of the image and vessels must be clearly visible within 1DD of the centre of the fovea. The specifications for a good quality disc centred image are the same but centred on the disc and with fine vessels clearly visible on the surface of the disc. Adequate images are those where the central feature, macula or disc, is at least 2DD from the edge of the image with vessels still visible within 1DD of the centre of the fovea (macular image) and fine vessels visible on the disc (disc centred image). Good quality images are shown in Figure 5. Ungradeable images don't meet these requirements unless there is referable retinopathy anywhere else in the eye. The Scottish Diabetic Screening Protocol requires a single 45° field including the entire optic disc and with the fovea more than 2DDs from the edge of the image. The clarity of the photograph must be sufficient so that the third generation of branching vessels are visible around the fovea.

Procurement and Supply Authority (PaSA) approved systems

Supply of camera systems and related screening management software is handled through the NHS and its Procurement and Supply Authority (PaSA). Cameras available for use within the National Screening Programme in England have been carefully evaluated against fixed criteria¹⁰. A re-procurement was

carried out in 2006 with the framework agreement running until April 2009. Seven systems are listed with the commercial digital camera listed in brackets:

i. Nidek AFC-210 (Canon EOS 5D)

Auto-focus fundus camera with the Canon EOS 5D DSLR incorporating a 12.8Mp near 35mm format CMOS sensor. The camera has the ability to store lossless (RAW - unprocessed) and lossy (JPEG) files.

ii. Canon CR DGi (Canon EOS 30D)

Canon's non-mydratic, 45 degree field of view fundus camera, with an image size of 17mm at the sensor plane. The Canon EOS 30D contains a 8.2Mp sensor measuring 22.5x15mm and again the ability to store lossless (RAW) and lossy (JPEG) file formats.

iii. Kowa non-myd 7 (Nikon D100)

Non-mydratic fundus camera with the ability to switch between 20 and 45 degree fields. The Nikon D100 has a 6 Mp CCD sensor giving a maximum pixel size of 3,008x2,000 over a 23.7x 15.5mm format. This camera is now discontinued.

iv. Topcon TRC NW6s (Nikon D80)

Digital fundus camera offering 30 and 45 degree fields and peripheral fixation points for flexibility. The Nikon D80 offers a 10.2Mp (3,872x 2,592 pixels) CCD sensor measuring 23.6x15.8 mm.

v. Topcon 3D OCT-1000

Topcon's Fourier Domain enables ocular coherence tomography (OCT) and is a non-mydratic fundus camera offering a 45 degree field and a working distance of 40.7mm. Topcon do not state the sensor resolution in their literature although it is integrated from the appearance of the instrument.

vi. Topcon TRC NW8 (Nikon D80)

The NW8 is the successor to the NW6s and offers increased ease of focusing and 30/45 degree fields. It can take a number of digital camera backs. The performance of the Nikon D80, which was approved with the NW8 as part of the framework agreement has been stated above under the NW6s.

vii. Zeiss Visucam NM Pro

Zeiss' non-mydratic fundus camera offers 45/30 degree fields, internal and external fixation and the ability to cope with 3.3mm pupils although only

for a 30 degree field (most other cameras can't go below 3.7mm). The integrated CCD sensor offers 5Mp resolution coupled with Zeiss' telecentric optics.

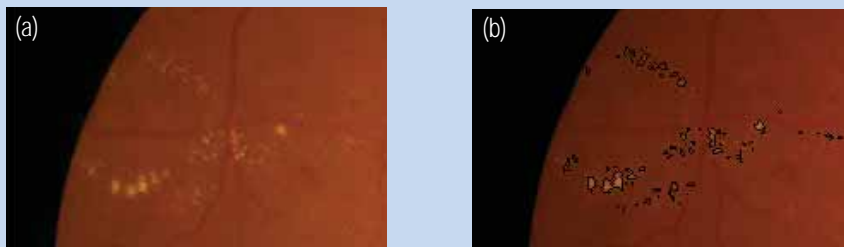
Automatic detection of diabetic retinopathy

There are approximately 2.5 million people with diabetes in the UK all at risk of developing sight-threatening retinopathy and requiring screening on an annual basis if over the age of 12 years. The potential benefits of automatic screening systems that can remove the clear "no disease" patients would be huge in terms of time and cost. Efforts to use digital image analysis for detecting specific ophthalmic signs in diabetic eye disease have been reported for over 20 years, initially using high resolution photographic transparencies that were scanned to provide the digital images. Over ten years ago, systems were reported that gave better than 80% sensitivity and specificity, so it is somewhat surprising that automatic screening systems are not available that meet the National Screening Framework requirement of 80% sensitivity and 95% specificity, the so-called Exeter Standard set by a meeting of Diabetes UK in 1984. Research suggests that no screening method (including manual grading) consistently meets these levels and it has remained in place for guidance only. Studies looking at screening using mydratic digital photography, report sensitivity and specificity values in excess of 85%, indicating that a required specificity of 95% could have been set too high. Studies looking at screening using trained graders report a sensitivity between 87-100% and a specificity of 83-96%. Consequently, any automated screening method needs to prove that it meets the Exeter Standard or comes at least as close as digital photography and manual grading.

One of the first points to address with diabetic screening is what is required of an automated screening system. Ideally, it would replace the grader and perform at least as well. This means it must first distinguish



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 ➔ **Figure 6**

Example of automatic detection of exudates¹²: (a) section of the original fundus image and (b) automatic detection of exudates using a mathematical morphology method (images courtesy of Akara Sopharak and Bunyarit Uyyanonvara, Thammasat University, Thailand and Sarah Barman, Kingston University)

retinopathy from no-retinopathy and then grade the retinopathy, if present. Early workers realised that it would first be necessary to identify the major components of the fundus: the optic disc, macula and vessels¹¹. Images could then be analysed for the location of lesions to find, for example, perifoveal exudation as well as indications of other sight-threatening conditions such as glaucoma and age-related macular degeneration. Sensitivity and specificity values were near 100% for the optic disc, falling to 83% and 91% respectively for the blood vessels. Different techniques are required for the different features: the optic disc, which was detected with the highest sensitivity and specificity, has a rapid change in contrast and colour at its boundary and is of a constant size. A clear definition of the feature being located helps the image processing algorithms probably explaining why the sensitivity and specificity scores were so high for the optic disc. An artificial neural network was used to define the blood vessels. An artificial neural network can learn from experience or “inputs”. As such, it develops its own rules for deciding whether a pixel in a fundus image is a vessel or a non-vessel. This approach is taken because it is clearly more difficult to write a definition that would allow vessels to be found unambiguously. The same workers then examined the ability to automatically detect haemorrhages and microaneurysms (treated as one group) and exudates. Sensitivity and specificity for exudate detection was 89% and 100%, and 78% and 89%

respectively for haemorrhages and microaneurysms. Again, these results may be predicted from the clearer appearance of the exudates with their higher contrast and colour difference from the background. One criticism of these early studies is that they didn't always use a large number of images to test the system. For example, in the last study, only 14 images contained haemorrhages and microaneurysms. It is perhaps surprising that ten years on from these early promising results that automatic screening at least for “no-refer/refer” has not been adopted. Some of the possible reasons include:

1. The lack of a gold standard. It would be ideal if all workers (there are approximately 30 institutes throughout the world working in this area) had a standard set of images for testing algorithms. In addition, manual grading is a useful comparison but should not be considered a gold standard.
2. Any screening system must be able to cope with eyes showing signs of other pathology.
3. An acceptance that the Exeter standard sets the bar too high and that a useful contribution can be made to “disease/no-disease” grading with current methods. A recent study from the Aberdeen group¹³ reported 90.5% sensitivity and 67.4% specificity for automated “disease/no-disease” screening using 14,406 images. However, the automatic system did pick up 99.8% of technical failures (better than manual grading) and 97.9% of patients with referable observable maculopathy/retinopathy. It can be argued that this has been

achieved by having a much lower specificity but the workload of graders has still been reduced.

New algorithms continue to be published for lesion detection (Figure 6)^{12,14,15} since each forms an important part of the detection process. However, evaluation of the whole process including how to potentially combine the results of four images from one patient to improve sensitivity and specificity are fundamentally important¹⁶. The results of these studies still produce vigorous debate in the literature between the various groups and there is no clear convergence of opinion that suggests automatic screening will be adopted in the near future even though it offers clear advantages particularly as a pre-screener to remove the obvious “no disease” cases. Such a system would have a lower specificity than the Exeter Standard but it would still reduce significantly the workload of diabetic screening and grading.

Conclusions

Digital imaging offers many advantages when screening for diabetic retinopathy and technology is more than adequate for the task. Current issues include the amount of image compression that can be applied without affecting detection of clinically significant features and whether high-resolution image sensors help compensate for image errors such as defocus or low light levels. There is still vigorous debate over the potential for automated screening for diabetic retinopathy although it could significantly cut down the workload of graders particularly for “disease/no disease” screening.

About the author

Chris Hull is head of the Department of Optometry and Visual Science at City University, London. He has a longstanding interest in digital imaging and image processing and has taught in this area on City University's MSc Optometric Management of Diabetes module for many years.

References

See www.optometry.co.uk/references



Module questions

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Please note, there is only one correct answer. Enter online or by the form provided

An answer return form is included in this issue. It should be completed and returned to CET initiatives (C-10558/0) OT, Ten Alps plc, 9 Savoy Street, London WC2E 7HR by July 10 2009

- The spatial sampling (resolution) of a digital bit-mapped image is set by the:
 - bit-depth
 - number of pixels across the image
 - camera optics
 - image sensor size
- Which one of the following statements about digital image sensors most closely applies to diabetic screening?
 - any sensor is suitable for diabetic screening
 - CCD sensors have a greater light sensitive area making them more appropriate for diabetic screening
 - CMOS offers the higher resolution required for diabetic screening
 - both CCD and CMOS technology are adequate for digital photography when screening for diabetic retinopathy
- A 24 bit-depth colour image can display 16,777,216 different colours. What is the best explanation of this?
 - it exceeds the maximum number of distinguishable colours by the human eye
 - each detector can record over 16million different colours
 - each detector can record 256 levels of red, green or blue which can be combined to give $256 \times 256 \times 256 = 16,777,216$ colours
 - it is the default Windows setting for displays
- The smallest clinically visible microaneurysm is generally considered to be:
 - 10 μm
 - 30 μm
 - 110 μm
 - 200 μm
- Which one of the following is incorrect regarding downsampling?
 - it reduces the pixel count of the image
 - it can be carried out within image processing software
 - it may involve bi-cubic interpolation
 - it increases the pixel count of the image
- What level of image compression is considered acceptable and does not result in loss of clinically significant information?
 - a compression ratio of 12:1 with no subsequent compression
 - a compression ratio of 20:1 with no subsequent compression
 - a compression ratio 37:1 is acceptable
 - a compression ratio of 37:1 but only using JPEG 2000
- Images for grading must be displayed:
 - only on a CRT monitor
 - on monitors with 1280 x 1024 resolution or higher
 - at 1 to 1 i.e. one image pixel to one display pixel
 - on monitors with 1600 x 1200 resolution or higher
- A disc-centred image where the disc is less than 2DD from the edge:
 - can be graded in all cases
 - can only be graded if there is referable retinopathy elsewhere in the eye
 - cannot be graded
 - is described as 'adequate' quality for grading
- Screening for diabetic retinopathy in the England, Wales and Northern Ireland requires:
 - seven field stereo images
 - one x 45 degree field centred on the macula
 - one x 45 degree field centred on the disc
 - two x 45 degree fields centred on the macula and disc respectively
- Which one of the following statements is incorrect regarding the supply of cameras for diabetic screening through the Procurement and Supply Authority (PaSA)?
 - a new contract is expected including newer camera models
 - seven cameras were approved
 - PaSA approved cameras have been tested against fixed criteria
 - only mydriatic cameras have been included
- What is the Exeter Standard for automated screening system?
 - 95% sensitivity and 100% specificity
 - 80% sensitivity and 95% specificity
 - 60% sensitivity and 75% specificity
 - 70% sensitivity and 85% specificity
- Which one of the following is incorrect? The advantages of using digital imaging to screen diabetic retinopathy include all of the following except:
 - low resolution colour images
 - backup of images
 - immediate viewing
 - easy to display successive screenings to see progression

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