OPTOMETRIC INSTRUMENTATION - AN INSIGHT INTO ANTERIOR IMAGING

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The term 'imaging' is used mostly to refer to the *recording* of a visual representation of an object. Many forms of imaging are used in ophthalmic assessments in order to improve our understanding and subsequent management of ocular conditions. This article will review the imaging processes that we use currently and highlight the latest developments in equipment.

Photography

The invention of photography in the eighteen hundreds was embraced by the medical community and the potential of the medium was recognised for its abilities to capture images of anatomical features both accurately and indefinitely. [1] However its use in optometric documentation was restricted outside of the Hospital Eye Service by the expense of the equipment and slow developing processes. [2] The advent of digital technology was to revolutionise medical imaging and removed many of the limitations of film-based photography allowing countless images to be captured and viewed instantly. The ease of use and applications for this technology encouraged rapid growth and competition for research and development. The high level of interest from the general public led to further advances in the technology which have resulted in highly developed but competitively priced camera systems.

Digital technology in brief

Both digital and traditional methods of photography begin in a similar fashion, as light passes through a lens and is registered by the medium within. For analogue cameras this medium is the film, a plastic strip coated in layers of chemicals including silver halide crystals, which form the light sensitive component. For digital image capture this medium is the 'chip' which contains photosites of light-sensitive diodes known as pixels. Pixels have the ability to absorb light photons and convert them into an electrical current. The conversion of this current into a level of volts is the second part of the capture process. The amount of volts is then assigned a numeric (binary) code each piece of which contributes to the pattern of units that is used to recreate the image optically. This system allows information to be transferred and copied indefinitely.

Colour information must be built from individual readings which can be obtained by the digital chips in various ways. The most commonly used chips in anterior imaging are the charged couple device (CCD) single matrix one-shot chips which has grid of photosites each coated in either red, green or blue to absorb the available light at specific wavelengths. These pixels are spatially arranged in a mosaic ‘Bayer’ pattern (Figure 1). The Bayer pattern provides twice as many green as red or blue pixels in order to imitate the human perception of colour, which has a greater resolving power in the green part of the spectrum. [3] Another form of chip is the triple matrix, one shot (often called three-chip cameras). Each of the 3 CCD chips captures an image of the scene at its full resolution, but through a different filter (red, green or blue). Prisms are used to divert light to 3 positions. These cameras are more expensive, delicate and bulky than single matrix cameras. Due to the light loss from the beam splitters they also require a higher light output from the slit-lamp for equivalent performance to the 1-chip. This is demonstrated by a comparison between the 2 cameras taking an image of the same eye in Figure 2.

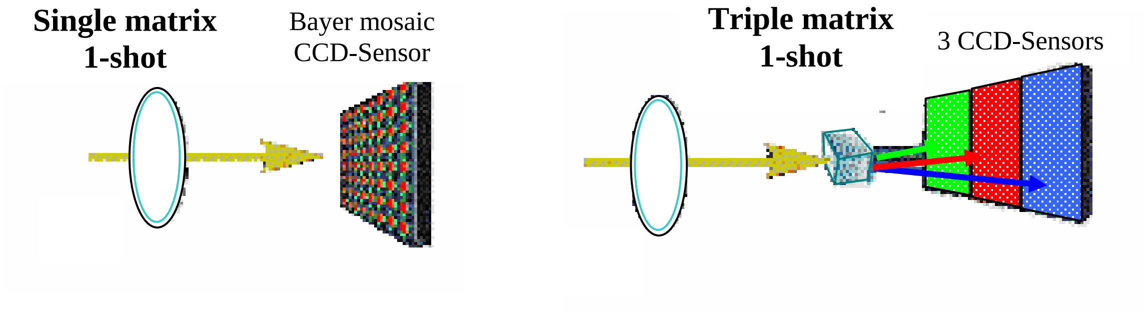


FIGURE 1: Single matrix 1 shot and single matrix 3 shot comparison [4]

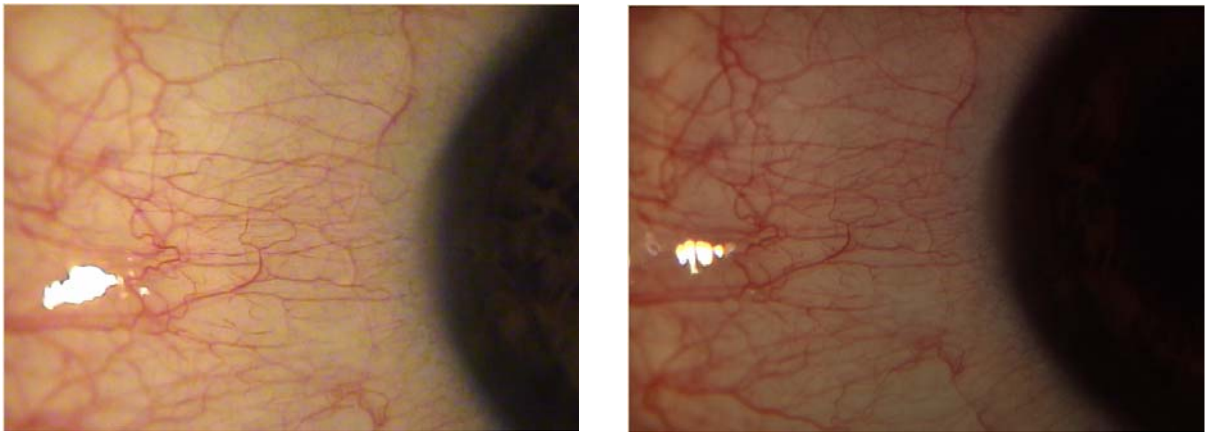


Image taken with 1-CCD chip **Image taken with 3-CCD chip**

FIGURE 2: Comparison of a resolution matched image from a 1-chip (JAI CV-53200, 767 x 569; Yokohama, Japan) and a 3-chip (JVC KYF58, 767 x 569; Yokohama, Japan) camera taken through the same slit lamp optics. The image on the right taken with the 3-chip camera is clearly much darker suffering from the 3-way split of luminance. Care should be taken if images captured with each camera type are to be compared, as subjectively, the grade of the hyperaemia appears to be different.

Two major considerations with digital imaging are the resolution needed to detect objects of interest, and the compression utilised to minimise the file size (by the removal of redundant information) and hence space needed for storage.

Resolution

Resolution is the ability to distinguish the difference between two sequential points. In digital imagery, this depends on the number of pixels that the image is composed of. [5]
If photographs are to be used to detect pathology, monitor progression and to protect against litigation, it is essential that the resolution is sufficient to allow all clinical features of interest to be detected and that this is not compromised by the image storage. However, if all images are taken at maximum quality, storage and archiving can slow a system down considerably as there is more processing needed with larger files. If this occurs, then one of the major advantages of digital technology may be compromised.

Research into the minimum resolution required to maintain good diagnostic integrity has indicated that an image of 767x569 pixels can be used without loss in subjective or objective grading sensitivity. [6] Therefore, the many video cameras used in anterior ophthalmic imaging (which often have resolutions of approximately 767x569 pixels -

commonly refreshed at 25 frames per second) offer adequate image quality for maintaining accurate evaluations of the anterior eye.

Compression

Image compression is a technique used to reduce file size, by removing redundant information. In some compression methods the full information can be retrieved (termed ‘lossless’ formats such as Tagged Information File Format or TIFF), but in others information is permanently deleted (‘lossy’ formats, such as Joint Photographic Experts Group or JPEG). Studies have suggested that a compression to 75% JPEG of the maximum image is acceptable and will cause no loss in subjective image quality. This level of compression will reduce the file size by approximately 97%. [6-7] If the file size is reduced by this amount by compression alone then image resolution will not need to be limited, however it is worth baring in mind that an image with a resolution higher than the screen that is used for viewing will cause interpolation of the image information and effectively reduce the quality of the image observed. [6]

Digital imaging in practice

Digital photography quickly proved invaluable in the study of ophthalmology when applied to tasks such as fluorescein angiograms and diabetic retinopathy screening. [6-8] The interest from clinicians has been driven from the need to record what is observed of the eye, both in monitoring conditions and in protection from litigation. It also provides an improved method of presenting cases seen and enthusing patients as to the quality of their eye care. The need to sketch interesting features is reduced and the digital images can be stored as part of a paperless patient record system.

The main advantages of digital imaging in practice include:

- The low cost of capturing many successive images in order to obtain the optimal photograph and to offer a more complete representation of any item of interest.
- Almost instantaneous viewing of the image allowing images to be retaken if they are not ideal. This is certainly an advantage in anterior ocular imaging as the minor movements made by the patient can disturb even the most carefully aligned view, especially at high magnifications.

- The ability to store images without printing out the hard-copies saves time, energy and space.
- An image or video clip may be transferred almost instantly to another party which offers the opportunity to back-up data on a separate secure system, or to be used in the future for telemedicine where practitioners could obtain second opinions instantly from ophthalmologists etc.
- A digital image is at its basic level a binary code which when it is transferred is not affected by electronic interference. This interference causes ‘noise’ or a distortion in the image when it is displayed which can occur with an analogue based transfer

However, digital cameras have been generally more expensive than the film-based equivalent and there is a delay between pressing the capture button and the image being taken, making them less useful for capturing fast moving or unstable objects. The high image resolutions that are usually associated with digital image capture can take a while to transfer from the light detection chip to the storage location, limiting the number of images that can be captured and displayed each second. When a live feed is required, the resulting delay can be jerky and may even have a slight time lag especially on some of the earlier models. This should become less of an issue as transfer technology from the imaging chip to the storage site improves.

Advances in slit lamp imaging

Although they are fundamentally based on the same design slit lamps have evolved considerably over the past 5 years and now offer better optics, filters and manoeuvrability than ever before. A more obvious change has also occurred in the general build of the systems which also have a higher standard of engineering than was previously found generally due to improved materials and manufacture methods. Slit lamp imaging was popular with film-based camera users especially in ophthalmology and now that digital technology reduces the cost and has improved availability of the systems other eye care practitioners are following suit. Anterior segment imaging can be considered more skilled than retinal imaging as the operator needs to be competent in slit-lamp biomicroscopy as well as photography. The slit-lamp and imaging system that is chosen by a practitioner is quite a personal choice. When purchasing a slit-lamp biomicroscope it is important to examine not only present needs, but also future aspirations in terms of level of usage, the type of optometric services you provide and possible imaging requirements. The range of instruments and features available is beyond the realm of this article however Figure 3 below displays some of the most recently available systems in the UK. Slit lamps A and B have a beam splitter and video camera attachment which allows video images to be transported to a monitor and then a still image from this real-time feed can be selected by the capture button on the joystick. Slit lamp C is one of the DC range where the digital camera is actually integrated into the build of the system. The difference between the DC systems is generally slit lamp related with a variety of magnification and structural options available. Image C shows a slit lamp attachment which in this case includes a video camera which would link into the supplied software. This method allows a practitioner the option of adapting a slit lamp with a variety of camera options which are fully removable, offering the option to use the camera in other settings. Slit lamp E also shows this format with a still camera attached above the eye-pieces. Other camera attachments are also available with this system.

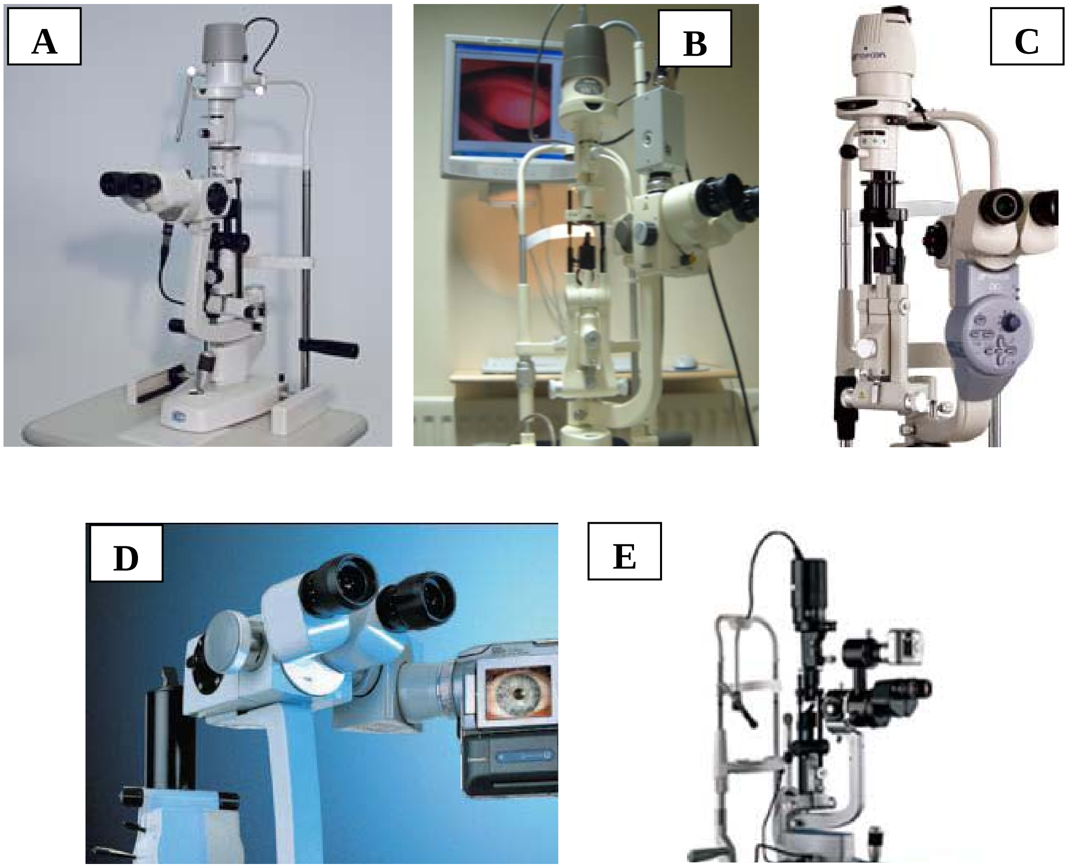


FIGURE 3. Digital slit lamps: A: CSO 990 (Birmingham Optical Group). B: Takagi SM-70 (Carleton Optical). C: Topcon SL-D7 (Topcon). D: Digicam Adapter (Zeiss). E: BP 900 (Haag Streit).

Software

Advances in the software available include the ability to communicate with the camera, so that a time and date stamp can be hidden in the image file when an image is taken, providing potential litigation protection. Most of the software systems on the market, such as Visupac by Zeiss, Navis by Nidek, ARC by ARC/Carleton and ImageNet by Topcon are relatively easy and intuitive to use. Any choice between them may therefore rely on personal preference or the support that is offered. For example, is tailoring to individual requirements possible and will free upgrades be provided. It is also vital to ensure that any new software is compatible with any present software that might be currently utilised (such as a practice management database) and if it can be driven through a network (allowing fast and efficient access to and storage of information throughout the practice).

Anterior ophthalmic imaging

As well as documenting the appearance of the anterior eye, digital imaging can be used to assess the anterior chamber depth and angle, intraocular lens positioning, posterior subcapsular thickening and to determine the central corneal thickness. The latter has increased in importance as its role in the measurement of intraocular pressure readings has been better understood and with the development of laser refractive surgery.

Topography

Topography is a measure of the corneal curvature. The most recently introduced instruments in practice are those based on placido-disc reflective imaging. The principle involves direction of light rings onto the corneal surface which acts like a convex mirror; the rings are reflected back onto a digital camera (CCD chip) (e.g. Figure 4). The subsequent image is then transferred to analysis software where the set distance from the cornea to the light source is used to calculate the exact distortion of the reflected curves and hence the corneal surface. A variety of formats is used to display the results but the most familiar is the colour contour map depicting changes in corneal radius or power. Advances in the topographic technology and imaging systems have allowed further development of these systems so that the back corneal surface curvatures can also be measured, and the corneal thickness ascertained (known as raster topography or posterior apical radius imaging) which has obvious applications for screening and measures prerefractive surgery. Accuracy of these techniques is high (4 to 7 µm in the central and peripheral cornea respectively and set to increase further as improvements in digital CCDs continue. [8]

FIGURE 4: EyeSys. Corneal placido topographer.

Tomography

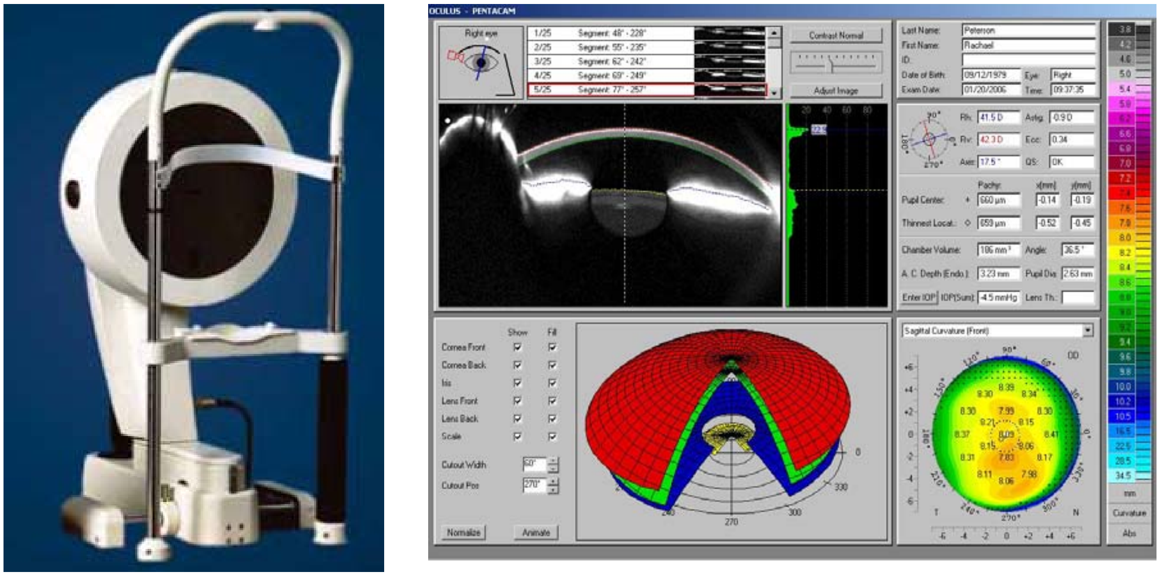
Tomography is a term used to describe imaging by sections. Various forms of this investigation are used in medical imaging such as computed tomography (CT) (previously known as computed axial tomography or CAT scans) which apply x-rays, or B-scan techniques which use sound. In ocular investigations optical coherence tomography (OCT) is used which is a non-invasive technique using reflection of light waves to obtain images with high spatial resolution (currently up to 1.3µm) [9] It is this high resolution that makes OCT ideal to examine the retinal layers and macular thickness or defects. In the anterior eye OCT has been applied to measures of the cornea and limbus, tear film thickness, anterior ocular structures such as the intra-ocular lens and to determine the chamber depth and irido-corneal angle (Figure 5). OCT can obtain images through some opaque tissue also, enabling investigation of the anterior chamber even through an opaque cornea, or through the human sclera for investigation of the ciliary body. [8, 10-14]

OCT works by splitting a light source into 2 beams, one for reference, and the other for measurement. Light from the measurement beam is reflected from the ocular structures or defects and interacts with the reference light (reflected from the reference mirror) which causes interference. Coherent (positive) interference is measured by an interferometer which allows an image of the reflected light from the ocular structures to be built-up. [14]

FIGURE 5: Optical coherent tomographer.

Scheimpflug Technique

Patented by Theodore Schiempflug in Vienna 1904 and applied to ophthalmology in the 1970s this technique allows the assessment of the anterior segment along a sagittal plane from the cornea to the posterior lens surface. [16] The principle involves imaging the eye with a slit-beam perpendicular to a camera chip creating an optic section of the cornea and lens. It allows images from various positions to be captured and can now be used to create a three-dimensional map of the anterior segment. This method is used in various equipment, the most recent of which to become available is the Pentacam (Oculus) see Figure 6. Applications include assessment of cataract, corneal haze, corneal curvature and corneal thickness. [17-23]



1/25 Segment: 48° - 228°
2/25 Segment: 55° - 235°
3/25 Segment: 62° - 242°
4/25 Segment: 69° - 249°
5/25 Segment: 77° - 257°

Last Name: Peterson
First Name: Rachael
ID:
Date of Birth: 09/12/1979 Eye: Right
Exam Date: 01/20/2006 Time: 09:37:35

Rh: 41.5 D Astig: 0.9 D
Rv: 42.3 D Ecc: 0.34
Axis: 17.5° QS: OK

	Pachy:	x[mm]	y[mm]
Pupil Center: +	660 µm	-0.14	-0.19
Thinnest Locat.: ◇	659 µm	-0.52	-0.45

Chamber Volume: 106 mm³ Angle: 36.5°
A. C. Depth (Endo.): 3.23 mm Pupil Dia: 2.63 mm
Enter IOP IOP(Sum): 4.5 mmHg Lens Th.:

	Show	Fill
Cornea Front	☑	☑
Cornea Back	☑	☑
Iris	☑	☑
Lens Front	☑	☑
Lens Back	☑	☑
Scale	☑	☑

Cutout Width: 60°
Cutout Pos: 270°

Sagittal Curvature (Front)

FIGURE 6: Scheimpflug device and a captured image of the anterior eye.

Ultrasonography

There are three main forms of ultrasound in ophthalmology: A-scans which obtain information regarding the relative positions of ocular structures along the optical axis, (this method allows measures of the axial length to be taken for use in determination of intra-ocular lens power prior to cataract extraction), B-scans which are used mainly for examination of the posterior segment, and ultrasonic biomicroscopy (UBM) which assesses the anterior segment and angle. It uses high frequency sound waves with a transducer which increases the resolution that can be obtained up to 50µm. The depth that this method of imaging can penetrate to is approximately 5mm which is sufficient to image the anterior segment but no further (Figure 7). [8]

FIGURE 7: Ultrasound anterior eye image.

Confocal Microscopy

Confocal microscopy is an 'in vivo' method of examination used frequently to examine the cornea. It uses the principles of the pin-hole to obtain high resolution images without restrictive aberrations and resolutions of up to 1µ can be obtained although this is limited to a small area. [8] Focus can be achieved on individual cells throughout the layers of the cornea where previously this level of cellular microscopy could only be obtained through ex-vivo techniques which limited the understanding of the function and processes involved in the corneal structures. Direct observations using this technique are used to evaluate the progression of pathology or its treatment in the cornea, and to assess corneal thickness and other factors affected by refractive surgical procedures. [24-29]

FIGURE 8: Confocal microscope

Conclusion

Digital technology has introduced the possibility of a dynamic and accessible tool into every day practice, the benefits of which include immediate and accurate imaging to improve diagnosis, assessment and protect against litigation. These advances in ophthalmic imaging over recent years will continue to further our knowledge and understanding of anterior surfaces and pathology.

Acknowledgement

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MCQ questions

1. A Bayer pattern consists of which proportion of coloured photosites:
    a. Equal quantities of red, green and blue
    b. Twice as many green as red or blue
    c. Twice as many red as green or blue
    d. Twice as many blue as green or red

2. What is compression:
    a. A form of recycling
    b. A type of JPEG
    c. The ability to distinguish between two sequential points
    d. A method of reducing file sizes

3. In topography the corneal surface acts like a:
    a. Convex mirror
    b. Concave mirror
    c. Placido ring
    d. Contour map

4. Optical coherence tomography can achieve spatial resolution of up to :
    a. 1.2 µm
    b. 1.3 µm
    c. 1.4 µm
    d. 1.5 µm

5. The Schiempflug technique is not capable of imaging the
    a. Anterior chamber
    b. Crystalline lens
    c. Back surface of the cornea
    d. Ciliary body

6. What is UBM
    a. A form of anterior photography
    b. A non-invasive method of examination used frequently to examine the cornea
    c. The assessment of the anterior segment along a sagittal plane
    d. Ultrasonic method of examining the anterior segment and angle

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