The ROYAL COLLEGE of OPHTHALMOLOGISTS

Ophthalmic Services Guidance

Ophthalmic Imaging

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1 Introduction

Ophthalmic imaging is an integral part of the work of all ophthalmic departments. It allows the clinician to record the findings from clinical ocular examination in an objective, reproducible, transmissible and durable manner. Many ophthalmic imaging devices also facilitate identification of anatomical and disease features that are not readily visible with standard examination techniques, and enable sophisticated quantitative analyses. As a result, ophthalmic imaging is essential to the diagnosis, treatment, and long-term monitoring of many ocular conditions. In addition, it plays a central role in ophthalmic disease screening, teaching, clinical trials and in virtual clinics and telemedicine.

Both the range and sophistication of ophthalmic imaging technologies have increased rapidly in recent years. This document provides an overview of the current state of commercially available ophthalmic imaging technologies and their clinical applications as things stand at the time of publication and **readers should note this is a rapidly changing field**. It also provides recommendations regarding minimum ophthalmic imaging requirements for hospital eye services. Finally, it touches on a number of important issues related to ophthalmic imaging, including information technology and information governance requirements, and the need for valid informed consent.

2 Corneal and anterior segment imaging

Anterior segment photography

The demand for anterior segment photography is considerably less than for retinal imaging, but this is an important technique for the documentation of anterior segment disease, and should be available in every eye department.

Corneal tomography:

Overview:

Corneal tomography is the mapping of corneal curvature across its entire surface. Corneal tomography has traditionally been performed using Placido-based systems, analysing multiple concentric rings of light reflected off the anterior corneal surface, and thus indirectly measuring corneal curvature. These systems allow measurement of the anterior corneal surface only.

More recently, direct measurements of corneal curvature have become possible, using scanning slit technology (Bausch & Lomb, Orbscan) or Scheimpflug imaging (Pentacam, Oculus). These systems allow evaluation of the posterior corneal surface and thus generation of corneal thickness maps, as well as greater coverage of the peripheral cornea.

Selected indications and requirements:

All units should have access to some form of this imaging device. Best practice management of keratoconus, including monitoring for disease progression, requires serial corneal tomography assessment. Even if corneal cross-linking is not available locally, referrals to units that can offer this treatment should be accompanied by topographical evidence of disease progression to enable treatment to be offered without further monitoring. Corneal tomography is also required in more complicated biometry calculations post-laser refractive

surgery, as well as in planning incisional refractive surgery, including astigmatic keratotomy post-keratoplasty.

Ocular wavefont analysis:

Overview:

Ocular wavefront analysis is a more specialised imaging modality particularly valuable to corneal surgeons.

Selected indications and requirements:

Ocular wavefront analysis will only be available in some highly specialised units that have laser refractive surgery facilities. Its primary use is in the planning of laser refractive treatments, and may also aid in the assessment of patients with dissatisfaction of their visual quality following previous ocular surgery (e.g. post-cataract surgery).

Specular microscopy:

Overview:

Specular microscopy is a non-contact technique allowing visualisation and analysis of the corneal endothelium.

Selected indications and requirements:

This technique is primarily used to monitor endothelial cell status pre- and post-corneal transplantation. Its use in supporting the clinical management of more general corneal disease is limited.

In vivo confocal microscopy:

Overview:

In vivo confocal microscopy, a pinhole aperture is used to focus a small point of light on the eye and also to collect light waves specifically reflected from this point. An array of such apertures can be used to examine many points simultaneously - this array is scanned rapidly across the field to create a two-dimensional corneal image. The device can then scan down through the cornea, creating a series of en face optical sections, allowing visualization of corneal microstructure at various depths.

In the UK, the most commonly used in vivo confocal microscopy system is the HRT Rostock Cornea Module (Heidelberg). This is a laser scanning (670nm) confocal microscope with lateral resolution and depth of field reported as 1µm and 4µm respectively.

Selected indications and requirements:

In vivo confocal microscopy is primarily used for the diagnosis of infectious keratitis, in particular for the detection of fungal elements and Acanthamoeba cysts. Early diagnosis of such conditions is often not possible with conventional clinical examination or microbiological investigations, leading to poor outcomes and significant morbidity for patients. Access to this imaging modality is recommended for tertiary referral corneal clinics. Assessment of the corneal endothelium is also possible with confocal microscopy:

this may be both qualitative (e.g. polymegathism in endothelial dystrophies) as well as quantitative (calculating cell density with in-built software analysis). In opaque or irregular corneas, where non-contact specular microscopy often fails to acquire a clear image, confocal microscopy is a more reliable tool and may obviate the need for a separate specular microscope. A significant limitation of this technology is that image acquisition and interpretation requires skilled and experienced personnel.

Corneal and anterior segment Optical Coherence Tomography (OCT):

Overview:

OCT uses interferometry to provide high resolution cross-sectional images of the cornea and anterior segment in a non-invasive manner. Anterior segment OCT is similar to posterior segment OCT although longer wavelengths light sources are more commonly used (typically ~1300nm versus ~800nm).

Anterior segment OCT devices were initially based on "time domain" technology e.g. Visante (Zeiss). These devices are gradually being replaced by "spectral domain" OCT devices with anterior segment modules (e.g. RTVue, Optovue and Spectralis, Heidelberg), and next generation "swept source" OCT devices (e.g. Casia). These devices offer improved resolution and greatly increased image acquisition speed for greater coverage of the corneal surface.

Selected indications and requirements:

The indications for anterior segment OCT are increasing rapidly and access to this modality is recommended for subspecialty eye clinics at tertiary referral centres. In glaucoma clinics, anterior segment OCT can be used for direct visualization of the anterior chamber angle, especially in patients with primary angle closure, and also for the diagnosis of patients with plateau iris configuration. In corneal and external disease clinics, it can be used to measure peripheral corneal thickness at multiple locations or the depth of anterior stromal corneal scarring useful for planning corneal transplantation surgery. It can provide measurements of anterior chamber depth prior to the insertion of phakic intraocular lenses. Post-operatively it can be used to assess the positioning and thickness of lamellar corneal grafts, the position of endothelial grafts and the assessment of post-LASIK corneal flap thickness.

3 Retinal imaging

Colour fundus photography:

Overview:

Specially modified cameras may be used to acquire photographs of the ocular fundus. In recent years, fundus cameras have become optimised for non-mydriatic image acquisition and have transitioned from analogue (i.e. film) to digital image capture. In such devices, a bright ring of white light is used to illuminate the ocular fundus – the light reflected is then captured on the pixel array of a charge-coupled device (CCD), and a digital image generated.

In combination with light filters and injections of intravenous contrast material, fundus cameras can be used to perform fundus fluorescein angiography (FFA) and indocyanine green angiography (ICG). In combination with light filters alone, they can also be used to perform monochromatic imaging and fundus autofluorescence.

In the UK, a wide range of fundus cameras are available, with commonly used examples including the Topcon TRC-50DX (Topcon) and the Zeiss FF450plus (Zeiss). These cameras are typically described by their optical field of view, with an angle of 30° or 35° most commonly used.

Selected indications and requirements:

The ability to acquire colour photographs of the ocular fundus is an essential requirement for all hospital eye services. Colour fundus photography is essential to the diagnosis and monitoring of most posterior segment diseases as well as for disease screening (e.g. as part of the national diabetic retinopathy screening programme in the UK). It is also commonly used in ophthalmic clinical trials and epidemiological studies.

4 Scanning laser ophthalmoscopy (SLO)

Overview:

SLO provides an alternative to fundus photography for the acquisition of posterior segment images. SLO devices employ a confocal (pinhole) aperture, generating a single point of laser light, at a specific wavelength, which can be scanned across the retina in a raster pattern (a series of parallel horizontal lines). As only a small area of the fundus is illuminated at any one time, the effects of light scatter are reduced and images with higher contrast are generated.

As SLO imaging utilises a laser light source at a specific wavelength, it is particularly well suited to monochromatic and fundus autofluorescent imaging (see below). In combination with intravenous injection of contrast agents, it can also be used to perform FFA and ICG imaging.

In the UK, commonly used SLO instruments include the Heidelberg Retina Angiograph-2 (HRA2) (Heidelberg Engineering) and the Nidek F-10 (Nidek).

Selected indications and requirements:

SLO imaging has many similar indications to that of colour fundus photography. However, as it offers many multi-modal imaging features, it is recommended for use in specialised ophthalmic services at tertiary referral hospital eye services.

Monochromatic imaging:

Overview:

Use of monochromatic light filters in fundus cameras allows images to be acquired using specific wavelengths of light. As described above, SLO devices can perform this function without additional filters as they employ laser light sources at fixed wavelengths.

The HRA2 (Heidelberg Engineering) system incorporates a “multicolour” mode, where separate fundal images are obtained with blue, green, and near-infrared filters, and which can then be examined individually or in combination.

Selected indications and requirements:

Longer wavelengths of light penetrate more deeply – the use of near infrared filters thus greatly improves visualization of subretinal and choroidal structures (e.g. drusen subtypes in age-related macular degeneration (AMD)). Conversely, shorter wavelengths of light such as blue light, allow improved imaging of superficial retinal structures (e.g. retinal nerve fibre layer defects in glaucoma and epiretinal membranes). Intermediate wavelengths of light, e.g. green light ("red-free"), provide optimal fundus images for general purposes. As red-free light is reflected by the retinal pigment epithelium (RPE), but absorbed by retinal haemorrhage and blood vessels, it is particularly useful for assessment of the latter.

Fundus autofluorescence (FAF):

Overview:

Many structures in the posterior segment possess innate fluorescent properties or "fundus autofluorescence" (FAF), that is, they fluoresce even in the absence of any exogenous contrast agent. By incorporating appropriate light filters, FAF images can be obtained with either fundus cameras or SLO devices. FAF properties are dependent on the wavelengths of light used:

1. when blue or green light is used, the dominant source of FAF is lipofuscin, a by-product of photoreceptor outer segment degradation that accumulates in RPE cells
2. when near-infrared light is used, melanin replaces lipofuscin as the dominant fluorophore

The SLO device most commonly used for FAF imaging is the HRA-2 "Blue-peak" autofluorescence system (Heidelberg Engineering), with an excitation wavelength of 488nm. FAF imaging can also be performed with the Optos ultrawide field SLO imaging system (see below). For FAF imaging with a fundus camera, longer wavelength filters are used to reduce the effects of lens autofluorescence (Spaide Autofluorescence Filters, Topcon: excitation: 535–580nm).

Selected indications and requirements:

FAF imaging is an essential requirement for specialised retinal clinics at tertiary referral hospital eye services. It plays a crucial role in the diagnosis and monitoring of patients with inherited retinal disease and in the assessment of patient with toxic retinopathies (e.g. hydroxychloroquine retinopathy). It also has an emerging role in the diagnosis and monitoring of geographic atrophy in patients with "dry" AMD.

Ultra-Widefield (UWF) imaging:

Overview:

Conventional fundus imaging, with a fundus camera or an SLO, typically utilises a 30° or 35° field of view. This allows optimal visualization of the posterior pole, but the more peripheral retina is not captured. However, recent advances in optics have greatly extending the field of view, known as ultra-widefield (UWF) imaging.

In the UK, the most widely used non-contact ultra-widefield imaging device is the Optos system (Optos). This system uses an SLO in combination with a large ellipsoid mirror to

obtain fundal images with a 200° field of view. In this manner, approximately 80% of the total retinal surface area can be visualized. A non-contact widefield (100°) imaging system has also been introduced by Heidelberg Engineering. As with standard fundal imaging, the use of appropriate light filters allows FAF and angiographic imaging.

Selected indications and requirements:

UWF imaging is of particular use in the assessment with complex posterior uveitis, retinal vascular diseases with significant peripheral non-perfusion, and in patients with peripheral chorioretinal tumours. As such it is recommended that specialised clinic in tertiary referral hospital eye services should have access to this technology.

Fundus Fluorescein Angiography (FFA):

Overview:

In FFA, a rapid series of fundus images are acquired following intravenous injection of a fluorescent contrast agent, sodium fluorescein. Fluorescein is stimulated by blue light (490nm) and emits green light (530 nm). FFA images are acquired using fundus camera or SLO devices incorporating blue excitation and yellow–green barrier filters. This aids visualisation of the retinal and choroidal vasculature.

Selected indications and requirements:

Access to FFA is an essential requirement for hospital eye services. Although FFA is less commonly performed in the era of OCT imaging, it still plays an important role in the assessment of retinal vascular diseases (e.g. diabetic retinopathy and retinal venous occlusions), choroidal neovascularization (e.g. “wet” AMD), macular diseases (e.g. central serous chorioretinopathy, posterior uveitis), and in the planning of laser procedures.

Indocyanine Green Angiography (ICG):

Overview:

ICG is usually performed in association with FFA, and is used to study the choroidal circulation. As ICG is 98% bound to serum proteins that do not pass through choriocapillaris vessel fenestrations, the larger choroidal vessels are not obscured by early leakage of dye from this layer. With an excitation peak at 810nm and emission of 830nm, the dye is excited by infrared radiation. The use of this long wavelength light enhances depth penetration, especially in cases of retinal haemorrhage.

Selected indications and requirements:

ICG is most commonly used for:

1. assessment of patients with “wet” AMD where the presence of polypoidal choroidal vasculopathy (PCV) is being queried; and
2. investigation of patients with complex posterior uveitis and white dot syndromes
3. the assessment of choroidal hyperpermeability in patients with central serous chorioretinopathy. ICG imaging is, therefore, an essential requirement for specialised retinal clinics at tertiary referral hospital eye services

Vitreous, Retinal and Choroidal Optical Coherence Tomography (OCT):

Overview:

OCT provides high-resolution images of the neurosensory retina in a non-invasive manner. OCT is analogous to ultrasonography, but measures light waves rather than sound waves. These measurements are achieved indirectly using interferometry. In this technique, the combination of light reflected from a tissue of interest, and light reflected from a reference path produces characteristic interference patterns dependent on the mismatch between the reflected waves. Since the time delay and amplitude of the reference path is known, the time delay and intensity of light returning from the sample tissue may be determined. The resulting plot of light intensity versus time delay is known as an A-scan and describes the anatomy of the eye tissue at a specific point. A-scans are then repeated at multiple transverse locations and mapped to a grey- or false-colour scale, giving rise to two-dimensional cross-sectional images (termed B-scans). On OCT false-colour B-scans, highly reflective tissue is reddish-white in colour, while hyporeflective tissue is blue-black in colour.

In the original OCT systems, interference patterns generated were varied as a function of time; such devices were commonly referred to as “time domain” OCT (e.g. Stratus OCT, Zeiss). In more recent OCT devices, the interference patterns generated are varied as a function of frequency, with such devices referred to as “spectral domain” OCT (e.g. 3D OCT, Topcon; Cirrus HD-OCT, Zeiss; Spectralis, Heidelberg). This results in greatly increased image acquisition speed. The next generation of OCT devices will employ tuneable lasers (“swept source” OCT) to further increase image acquisition speed, and employ longer wavelengths of light (e.g. 1050nm) to allow improved depth penetration (e.g. DRI OCT-1, Topcon).

Each OCT device incorporates image analysis software that provides measurement of retinal thickness via automated detection (“segmentation”) of the inner and outer retinal boundaries. Using these techniques, it is possible to measure retinal thickness at multiple locations and to construct retinal thickness maps corresponding to the Early Treatment of Diabetic Retinopathy Study (ETDRS) subfields.

Selected indications and requirements:

Access to OCT imaging is an essential requirement for hospital eye services in the UK. OCT imaging plays a central role in the detection, diagnosis, and long-term monitoring of nearly all posterior segment diseases. It also plays an important role in the assessment of unexplained visual loss in patients with normal biomicroscopic examination, particularly when combined with FAF imaging.

Optical Coherence Tomography Angiography (OCTA):

Overview:

Optical coherence tomography angiography (OCTA) is an emerging application for OCT which allows for high resolution imaging of the retinal vasculature (and to a lesser extent the choroidal vasculature) without the intravenous injection of a contrast agent. It relies on the

high speed of recent spectral domain and swept source OCT systems to map the flow of blood in the retina and choroid. To do this, multiple OCT scans are obtained in the same fundus locations over short periods of time. The flow of blood through these sections can then be detected through its effect on the reflected light (each system uses a different method, ranging from changes in phase to those of speckle noise or amplitude).

Currently, OCTA systems are commercially available from Optovue (AngioVue), Zeiss (AngioPlex), Topcon (Triton), and Nidek (RS-3000 Advance), with other devices likely to be forthcoming in the near future (e.g. Heidelberg OCT2).

Selected indications and requirements:

OCTA is an exciting technology, but is still in a relatively early stage in its development. Commercially available OCTA systems are still limited by a limited field of view relative to conventional FFA imaging, and by the presence of image artefacts. These image artefacts occur due to eye movements in patients with poor fixation, or due to limitations inherent in the technology (e.g. so-called "projection" artefacts). As a result, access to OCTA technology is not yet a requirement for hospital eye services. In the future, it is likely that all new conventional OCT devices will incorporate OCTA features as a matter of course.

Adaptive optics:

Overview:

The transverse optical resolution of fundus cameras, SLO, and OCT devices is limited by the presence of defects, or aberrations, in the optical system of the eye. Real-time measurement of these aberrations is now possible using a Hartman Shack wavefront sensor and, once measured, highly deformable mirrors can be used to compensate for these aberrations. By incorporating wavefront sensing and correction into existing optical imaging platforms – "adaptive optics" – it is possible to acquire images of the retina with cellular-level resolution, in a non-invasive fashion. Cone photoreceptors are the dominant feature seen with adaptive optics systems. Rods are smaller and less easily seen. Adaptive optics systems can also be used to evaluate the retinal vasculature and the ganglion cell axons in the retinal nerve fibre layer.

Adaptive optics has been incorporated into both fundus camera and SLO systems. Adaptive optics "flood-illuminated" fundus cameras are now commercially available and approved for use in clinical settings (e.g. "rtx1 Adaptive Optics Retinal Camera", Imagine Eyes).

Selected indications and requirements:

Adaptive optics systems are typically used in research studies to evaluate the integrity of the photoreceptor mosaic. They are limited by a small field of view (e.g. 4° x 4°). It is also time-consuming to both obtain and to analyse the images. Therefore, adaptive optics systems are not yet recommended for routine clinical practice in hospital eye services.

Laser Doppler Flowmetry:

Overview:

Measurement of the Doppler effect can also be used for calculation of ocular blood flow velocities. If the diameter of the blood vessel is known, then absolute values for blood flow volume may also be determined. A number of laser Doppler devices have previously been

developed for this purpose (e.g. the Canon Laser Blood Flowmeter and the Heidelberg Retina Flowmeter), but concerns about validation and clinical applicability have prevented widespread adoption. These devices are not recommended for routine clinical practice in hospital eye services.

Retinal oximetry:

Overview:

In spectral imaging, measurement of light reflected from the retina at multiple wavelengths is used to assess retinal oxygen saturation. A multispectral imaging device (Oxymap T1, Iceland) is available for research purposes and hyperspectral devices are in development, however detailed validation and reproducibility assessments are required prior to future routine clinical usage. These devices are not recommended for routine clinical practice in hospital eye services

5 Optic nerve head and peripapillary imaging

Optic disc photography:

Overview:

Optic disc photography is the longest established modality for glaucoma imaging and was the mainstay until the advent of semi-automated quantitative imaging devices more than two decades ago. Optic disc photographs may be acquired monoscopically with any commercially available digital fundus camera. Stereoscopic images may be acquired using a 'sequential' method where two images are taken in sequence with an angular difference in the plane of acquisition; the two 'offset images' can then be viewed stereoscopically using a stereoviewer. Sequential stereo photographs are difficult to acquire and many units will preferentially use monoscopic images or use a commercially available simultaneous stereocamera (e.g. Kowa, Nidek systems). For the latter, there are device specific requirements including specialised monitors and viewing systems that are needed to achieve a stereoscopic view.

An advantage of digital disc photography is that the images acquired are a genuine representation of the clinical optic disc appearance. Furthermore, disc photography reliably captures the presence of disc haemorrhages. Stereophotographic images have the additional advantage that three dimensional components of optic disc anatomy, such as disc slope and vessel angulation, can be appreciated. A significant disadvantage of optic disc photographs is that there is a high degree of inter-observer variability even amongst highly experienced observers, which is a particular issue for longitudinal monitoring. Software packages that allow planimetric, quantitative assessment of optic disc photographs may be used to reduce the subjective variability but these are not widely used in clinical practice.

Selected indications and requirements:

The current NICE guidance for Chronic Open Angle Glaucoma (COAG) recommends the acquisition of an optic disc image (regardless of modality) at the time of first attendance, with a new image being acquired when there is a clinical impression that progression has occurred. This is perhaps the main indication for optic disc photography in current clinical practice. The acquisition of a baseline optic disc photograph is particularly useful where a

patient is discharged back to routine optometric practice; the photograph may be used for reference should the patient be referred back to the hospital eye service at a later date.

Scanning laser tomography:

Overview:

The use of a confocal aperture in SLO devices allows acquisition of images at different focal planes within a tissue of interest (i.e. generation of a "stack" of en face images). Three-dimensional reconstruction of these images then allows tomographic (cross-sectional) visualization of the ocular fundus, albeit at a lower resolution than OCT. After acquisition, the stack of confocal images is aligned and their reflectivities summed, generating a false-colour, topographic image. The HRT software then calculates detailed measurements of optic nerve head morphology (e.g. disc and cup area). These stereometric parameters are compared with a normative database and risk of glaucoma assessed using a regression model (Moorfields Regression Analysis). The topographic image is then divided into six sectors; a green tick within a sector indicates it is within normal limits, a yellow exclamation mark borderline, and a red cross outside normal limits.

The Heidelberg Retina Tomograph-3 (HRT-3, Heidelberg Engineering) is an SLO device that allows for three-dimensional reconstruction of the optic nerve head.

Selected indications and requirements:

Since the introduction of OCT imaging, scanning laser tomography is expected to become less pre-eminent in the assessment of patients with glaucoma and optic nerve head pathology. Nevertheless, it can be helpful to distinguish normal optic disc anatomy from glaucomatous optic neuropathy, and to monitor progression of glaucomatous optic neuropathy. The best established 'classification' algorithm for the HRT is the Moorfields Regression Analysis which assesses neuroretinal rim in the context of age and optic disc size comparing with a normative database. The topographical change analysis algorithm is useful for the monitoring of glaucomatous progression. There is also a trend analysis algorithm but this is limited in that it does not allow a calculation of rate of change. HRT should continue to be used for monitoring purposes in units where it is already an established device.

Scanning laser polarimetry:

Overview:

Due to the parallel arrangement of its axons, the Retinal Nerve Fibre Layer (RNFL) is birefringent (a ray of light entering a birefringent substance is broken into two rays). Polarised light reflected from the RNFL undergoes a phase shift dependent on the amount of birefringent material present. Scanning of polarized light across a region centred on the optic nerve head can, therefore, be used to estimate RNFL thickness. The GDx was the only commercially available device. It is no longer marketed by Zeiss.

Selected indications and requirements:

Measurements of the RNFL by scanning laser polarimetry has been largely superseded by measurements using OCT (see below), furthermore it is no longer commercially available. As a result, scanning laser polarimetry is not a requirement and not recommended for hospital eye services.

Optic nerve head and peripapillary Optical Coherence Tomography:

Overview:

In patients with glaucoma, a single circular B-scan, centred on the optic disc is typically obtained. Segmentation (automated delineation) of the inner and outer boundaries of the RNFL on this scan then allows measurement of peripapillary RNFL thickness. The presence of glaucomatous thinning can then be determined by comparison with normative databases. OCT may also sample neuroretinal rim parameters within the optic disc. The most 'accurate' and reliable of these measurements is the 'Minimum Rim Width' (BMO-MRW) parameter featured in the Heidelberg Spectralis. As with peripapillary RNFL thickness, rim parameters can be used to help a clinician define whether a nerve is normal or glaucomatous by comparison with an age matched normative database. Macular thickness parameters (including ganglion cell complex measurements) may also be used to assess likelihood of a glaucoma diagnosis, by comparison with a normative database. Progression algorithms are available to monitor the progression of RNFL, neuroretinal rim and macular thickness over time.

Selected indications and requirements:

OCT imaging of the optic disc and peripapillary nerve fibre layer (+/- macula) can be undertaken as part of the baseline assessment of patients referred with suspected glaucoma. State of the art glaucoma imaging platforms (e.g. Zeiss Cirrus, Heidelberg Spectralis) incorporate sampling of all three anatomical sites (i.e. disc, peripapillary and macula). In terms of using OCT to monitor glaucomatous progression, it will be most effective in early to moderate glaucoma. It is of no utility in advanced glaucoma (because of the floor effect of RNFL thickness with advanced glaucoma). Repeat OCT imaging can be used to monitor ocular hypertensive, glaucoma and glaucoma suspect patients and, if used for such, the frequency of imaging should be proportional to the risk of progression.

6 External, oculoplastic and adnexal imaging

External Photography:

High quality facial pictures, adnexal and eye movement photography should be available in all hospital eye services, whether undertaken in the department or in a department of medical illustration. External imaging is an essential tool to evaluate progression of adnexal disease and to record surgical outcomes. It is essential that the pictures are standardised to ensure internal consistency between serial images. This requires perspective, exposure and ambient lighting to remain constant and adequate training must be provided.

3D Digital Stereophotogrammetry:

The orbital applications of more modern technologies such as quantitative 3D surface mapping of the face and orbit (Canfield Vectra 3D), are currently being evaluated. These technologies have the potential to evaluate orbital volume changes over time, which is a key pathological feature in the development of many forms of orbital inflammatory disease such

as thyroid eye disease, as well as orbital tumours. 3D mapping may also be useful in evaluating outcomes from orbital decompression surgery but this imaging is not currently available for routine clinical use.

7 Ultrasonography

Ocular and Orbital Ultrasound:

Overview:

Ultrasound is acoustic energy with frequencies above the audible limit. Very high frequency, low energy and short duration ultrasonic pulses are transmitted into the ocular and orbital structures from a 'probe'[1] via a coupling agent. In the time intervals between pulse transmissions, reflections from tissues are received by the same probe and the signals can be used to produce various types of detailed images of the eye and orbit.

Access to ocular ultrasound is an essential requirement for all hospital eye services.

Main Indications for ultrasound examination:

- Measurement of eyes with very dense cataract
- Diagnosis in the presence of opaque ocular media
- Aid in diagnosis in eyes with atypical clinical appearances.
- Diagnosis and measurement of tumours.

A-Scan

The A-scan technique produces a graphical output of echo amplitude versus distance in the eye. Nowadays, this technique is used only occasionally. It can be used to measure the length of the eye in the presence of a dense cataract when measurement by optical means is not possible. A small single transducer typically with a frequency of 10MegaHertz (MHz) is placed on the central cornea and aimed along the visual axis. It emits pulses of sound and in the time interval between pulses, the echoes are received by the same single transducer. Echoes are plotted as spikes on a display, the height of the spike indicating the amplitude of the echo and the position on the X-axis indicates the time of receiving the echo. A knowledge of the velocities of sound in the ocular tissues allows arrival times of echoes to be converted into distances. Coupling with these small transducers can just be the tear film, a liquid gel or saline bath.

B-Scan

The B-scan technique produces a cross-sectional image of the eye and obit. The B-scan is created by moving an individual transducer, via a coupling agent, across the eye. Each

[1] A 'probe' may be a single ultrasound emitting transducer or a bank of several hundred transducers (an array).

transducer position generates an A-scan line of data but instead of plotting echoes as spikes, they are plotted as spots, the brightness of the spots indicating the amplitude of the echo. These spots are plotted in accordance with the transducer position and so the image generated resembles an anatomical cross-section through the eye and orbit. If a machine has a good grey scale display, a wide range of echo amplitudes can be differentiated on the screen. If the transducer is moved rapidly, a 'real-time' image is generated and any eye movements of the eye will induce movements of abnormalities and their echoes on the screen.

A whole series of B-scan cross sections are obtained by the interpreter to mentally build a 3D image of the eye and orbit. Measurements (including axial length) can be taken from static B-mode images. Dynamic studies are vital in diagnosis and are performed on single B-mode sections by asking the patient to deviate the globe and observing the aftermovements of abnormal echoes.

Dedicated eye scanners use a single transducer which is placed in an enclosed column of water or oil and mechanically oscillated through an angle. Frequencies used to examine pathology in dedicated eye and orbit scanners are typically in the range 10MHz to 12MHz. Coupling is often on the open anaesthetised eye via a liquid coupling gel.

Images are trapezoidal in shape and convention shows cornea on the left of the screen.

Whole body B- scanners are much more sophisticated machines and can be used on any body part by selecting a probe with appropriate frequency and footprint size. These probes (arrays) are comprised of hundreds of transducer elements which can be triggered electronically in overlapping batches to simulate a single moving transducer. This allows very sophisticated signal processing. A typical probe for the eye and orbit would be 14MHz and sensitivity is much higher than a dedicated eye scanner and allows examination through a closed lid with coupling gel on the eyelid. No anaesthetic is required. Grey scale displays are high quality on these systems.

Images can be either rectangular or trapezoidal in shape depending on the probe and the convention is to show the cornea at the top of the screen.

Ultrasound biomicroscopy (UBM)

An Ultrasound biomicroscope is a dedicated ophthalmic B-scanner which uses a very high frequency single transducer (typically 35MHz-100MHz). The transducer is often not enclosed in a column but coupled to the open eye by a saline/gel bath to avoid a sound absorption in the enclosure. The UBM is useful for examining only the anterior few millimetres of the globe. High frequencies enable shorter ultrasonic pulses to be generated. The shorter the pulse the better the resolution. However, the higher frequencies are preferentially absorbed so the penetration of ultrasound is extremely poor at these frequencies.

Anterior segment OCT is now used for most anterior imaging. Very occasionally UBM can be useful when the cornea is fully opaque or if the OCT sensitivity proves inadequate for purpose.

Colour flow mapping (CFM) and spectral Doppler techniques

These techniques are available only on whole body scanners and allows imaging of movement in selected regions of the B-Scan with the eye held static. CFM is typically used for imaging blood flow in retinal detachments and tumours. Convention is for blood flow towards the probe to be shown in red shades and away from the probe in blues. If velocities of blood flow are required then a small gate is placed on the image and a graphical display (the Spectrogram or Spectrograph) is dual plotted below the image with the X-axis as time and the Y-axis as velocity. This useful technique is mainly used in subspecialty eye clinics at tertiary referral centres.

8 Other considerations

With an ever increasing number of digital imaging devices found within every eye hospital and eye department, it is essential that patient data is available to all clinicians to aid informed decision making and that this data is managed effectively. It goes without saying that clinicians must have easy access to computer terminals to view clinical images as they examine and treat patients.

The key to ensuring that patient data is available is the ability of computer systems or software to exchange and make use of information – known as interoperability – and this must be considered when making any new device purchase. This document will address interoperability and the key aspects of back-end infrastructure requirements, networking, connectivity, patient data storage and links with electronic medical records systems

Networking:

All new medical imaging devices must be networkable and have the ability to save data to a network storage location. It is no longer acceptable to have patient data saved locally on the PC of the capture device, as this presents as an information governance risk. Most devices and PCs will connect to the hospital network via an Ethernet cable. It is often commonplace to have viewer software supplied by the manufacturer of the medical device to enable clinicians to use Trust PCs to view patient data saved to the application patient database.

Connectivity and digital imaging and communications in medicine (DICOM):

The common format for digital imaging files is DICOM. Having a common format aids connectivity of different modalities and manufacturers' devices. All new medical devices need to be able to output files in a DICOM format to ensure interoperability and help with data storage.

Data storage, picture archiving and communication system (PACS):

Most instrument suppliers will provide software that includes a patient database that will be hosted on a server, and a data folder that will be located on a storage device (Storage Area Network 'SAN' or similar). With continued advancements in imaging technology, this often means that the volume of patient data being captured and stored is ever increasing in size – it's not uncommon for standard OCT scans to be 15MB and SWEPT source OCT scans to be

50MB plus in size. When planning storage requirements you need to consider storage space in multiple terabytes (TBs) taking into consideration patient data file sizes and patient throughput. Remember that for all of the live data being stored, there is the same amount again being stored on a data backup drive.

The best way to ensure connectivity between multiple modalities, and to enable the clinician to consider the data from multiple modalities in a single report, is by way of a PACS system. PACS will enable the end user to access all patient data from one system, significantly speeding up patient throughput and promoting a paperless environment.

Electronic medical records (EMR):

EMR systems are now commonplace in most hospitals and are used to replace paper records and for automatic reminders, e-prescribing and medication tracking and procedure coding amongst other functions. It is essential that the EMR system and PACS system link together to ensure that patient demographics are only entered once, thus saving time and reducing the risk of clerical errors.

Summary:

We need to ensure that all of the above is considered when purchasing new medical devices and software applications and when reviewing existing medical devices, software applications and infrastructure. Patient data, and the management of patient data to ensure the very best outcomes for our patients, is at the centre of everything that we do – and the more robust and interoperable we make our hardware and software systems, the better for all concerned and the very best patient outcomes will be achieved.

9 Information governance

All images, whether still or video, form part of the patient record and should be stored accordingly. Images, as much as any part of the record need to be confidential, accurate and clear. Clinical staff and those in charge of relevant imaging equipment and IT systems much be familiar with, and follow, the confidentiality, data protection and record management policies and procedures of their workplace and know where to get advice on these issues. It is good practice to have specific guidance on handling medical images. Particular care should be taken with images used for teaching purposes and those stored on laptops, memory sticks or similar portable devices. These must be encrypted and comply with local policy and the law. There are significant fines and potential legal consequences for mishandling patient identifiable information.

10 Telemedicine and virtual clinics

With increasing demand for ophthalmic care and difficulties in providing enough capacity in hospital outpatient ophthalmic clinics, and the encouragement of networked care and shared community care in the NHS Five Year Forward View, it is likely that patients' care may be increasingly shared between different providers across primary, secondary and tertiary

care and that the virtual review of technician obtained clinical data by clinicians (virtual clinics) will expand considerably. This will all need to be underpinned by the easy availability and secure transmission of clinical data including images. The principles of information governance and IT systems outlined will become increasingly important and more challenging to achieve but this will need to be overcome to ensure the UK ophthalmic community can care in a timely manner for all its patients.

11 Consent

Consent needs to be obtained for imaging as for any examination but usually this will take the form of either implied consent or verbal consent, as one would do for example when instilling drops or measuring the IOP in clinic. Written consent is not required to obtain images performed for clinical care nor to use these images for quality and governance purposes (e.g. to access for clinical audit). However, for publication (e.g. in a scientific journal), to show other patients (e.g. for leaflets, or for pre and post op comparisons for other patients considering a procedure) and even, strictly speaking, to use a patient's images for teaching colleagues, consent is required and this should be written formal consent. Some units use a consent form specific for imaging purposes and this is particularly important when the patient might be identifiable from the image.

12 Staffing

In the modern, high volume ophthalmic practice, the bulk of routine imaging should be performed by trained technicians, photographers and health care assistants. It is important that there is a sufficient sessional commitment from photographers and technicians to provide a reasonably seamless service, to prevent the build-up of waiting lists of patients requiring angiography, and to provide an urgent service. For preference, it is in the patient's interest that the service is available on demand, without the need for an additional appointment and availability must be sufficient to ensure no delay to treatment. It is also important to ensure where dye injection techniques such as FFA are used, there must be suitable resuscitation equipment and skills.

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