PERSPECTIVE

New applications in ultrasound technology

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As the old millennium nears its conclusion it would be appropriate to look back at the history of ultrasound in ophthalmology, examine its current applications, and consider the new developments in this field that will introduce it into the new millennium.

Historical perspective

It is only 50 years since ultrasound was first introduced to medical diagnosis; an astonishingly short period bearing in mind the impact this technique has exerted on all aspect of medical practices, including ophthalmology.

In our field, the early pioneers of ophthalmic ultrasound include Mundt and Hughes,[1] Oksala and Lehtinen,[2] and Gernet.[3] Those workers are credited with the introduction of time-amplitude A-scan. Oksala was the first to produce results on the speed of sound in various ocular structures, and Gernet described the application of this technique in axial eye length measurements. Ossoinig[4] worked extensively on the refinement and "standardisation" of A-scan and on its utilisation in tissue diagnosis.[5] The fundamentals of standardised A-scan include a precise S-shaped sound amplification curve, a transducer emitting non-focused beam, and the external calibration of decibel gain by mean of "tissue model". The technique of "standardised echography" as described by Ossoinig incorporates standardised A-scan, B-scan, and hand held continuous wave Doppler. This instrument combination coupled with well prescribed methods of examination is considered by many workers as the most accurate and reliable method of diagnostic ophthalmic ultrasound to date.

Baum and Greenwood[6] jointly reported the first application of "brightness modulated" B-scan in ophthalmology. They employed an immersion method. In 1972 Bronson and Turner described the first contact B-scan,[7] making ultrasound an easy and patient friendly imaging modality. This, and other significant work by Purnell[8] and Coleman *et al*,[9] led to major expansion and popularisation of B-scan.

The more recent development of duplex scanners and colour Doppler instruments in the 1980s has facilitated their use in ophthalmology. Workers such as Sergott, Leib, Williamson, Baxter, and Guthoff were responsible for the wider application of Doppler to ophthalmology.[10–12]

In 1990 Pavlin and colleagues described the first high frequency ultrasound (50–100 MHz) in ophthalmology[13] and in 1991 published its clinical application in imaging of the anterior eye segment.[14] The term ultrasound biomicroscopy (UBM) as coined by Pavlin is indicative of the high degree of magnification attained by this technique. Clear, near microscopic, in vivo images of the anterior segment, iris, ciliary body, and subsurface layers of the sclera and pars plana are now produced on UBM in such a way not previously possible on conventional B-scan.

Buschmann and colleagues founded the international society for diagnostic ophthalmic ultrasound (SIDUO) in 1964. The society contains more than 500 members worldwide and is thought to be the oldest ultrasound forum of any medical specialty. SIDUO international congresses are held regularly every 2 years.

Current application

Recent advances in instrument design and specifications have resulted in the production of high quality, eye dedicated, ultrasound scanners incorporating slim B-scan probes, excellent "real time" kinetic properties, and high resolution images. The analogue-digital conversion of A and B-scan images allowed us the luxury of freeze frame facilities and easy recording of echograms on video and digital format. Now, ultrasound is considered an essential tool in the investigation and management of many ocular and orbital disorders.[15 16]

In the eye, it is most frequently used to measure axial eye length for estimation of intraocular lens (IOL) power (biometry). Other ocular applications include screening of eyes with opaque media, diagnosis of complex vitreoretinal conditions, and differentiation of intraocular masses. UBM has allowed us to investigate subtypes of glaucoma, lesions in the iris, ciliary body, sclera, and par plana.[17]

In the orbit, ultrasound, including Doppler, is used for the investigation of extraocular muscles[18 19] and retrobulbar optic nerve diseases,[20 21] vascular anomalies,[22] and orbital mass lesions.[23 24]

BIOMETRY

No modern cataract surgery is now possible without accurate calculation of IOL power. In addition to keratometry, ultrasonic measurement of axial eye length is the most vital component of all formulas used to estimate IOL power. It is well recognised that a 1.00 mm error in axial eye length measurement results in a 2–3 dioptre shift in postoperative refraction.

New modified "theoretical formulas" have been produced and based on calculation of corneal refractive power, estimated postoperative anterior chamber depth (ACD), and axial eye length.[25] The new "regression formulas" rely on corneal refractive power, axial eye length, and a "correction factor" that is determined by the surgeon and IOL type.[26]

Modern theoretical and regression formulas are shown to be more accurate than older formulas in estimating IOL powers in short (less than 22 mm) and long (more than 25 mm) eyes.[27] In addition, recent studies have been published on the accurate speed of sound in various ocular media, including IOL materials (Table 1).[28] The results of large series of biometry have showed high predictive values of IOL power calculation and postoperative refraction.[29]

DIAGNOSTIC OCULAR ULTRASOUND

The importance of ultrasound scanning of eyes with opaque media is well established. Common examples include eyes with dense cataract and vitreous haemorrhage.

The following is an original study that illustrates the role of ultrasonography in the diagnosis and management of vitreous haemorrhage.

Purpose

The study was set up to assess the value of ultrasonography in vitreous haemorrhage (VH) by determining its diagnostic accuracy, its ability to identify the "cause of VH" and, consequently, influence the course of management.

Methods

A retrospective analysis of ultrasound and case records of all patients referred to the echography clinic, Aberdeen Royal Infirmary, with the clinical diagnosis of vitreous haemorrhage over a 3 year period between 1996 and 1998.

The clinical notes and ultrasound request form were examined to establish:

(1) if VH is clinically identified
(2) if a cause for VH is clinically determined
(3) if no cause could be clinically determined.

The ultrasound records were examined to establish:

(1) if VH is echographically confirmed
(2) if ultrasound examination identified a cause that was not determined or incorrectly determined clinically.

The definitive cause, if found, was established by one or more of the following:

(1) vitreous haemorrhage cleared to allow clinical identification
(2) vitrectomy.

The method of standardised echography was used in all cases. High gain followed by low gain B-scan screening was carried out. Scanning of the entire globe, including the fundus periphery, was made. Particular attention was paid to the topography of vitreous cavity, posterior hyaloid face, optic nerve head, and macular region. Kinetic echography was employed to detect vitreoretinal relation (traction), especially at the periphery, to detect retinal breaks. Standardised A-scan was utilised when differentiation of membranous opacities is required. The minimum follow up period was 6 months after the last ultrasound examination.

Results

A total of 66 cases of VH were clinically diagnosed and correctly identified on ultrasound. There were no incorrect diagnoses of VH.

In 48 cases (73%) a cause was identified on ultrasound. Out of these, a definitive diagnosis was established in 42 cases (88%). In the remaining six cases (12%), although an abnormality, other than VH, was identified on ultrasound, no definitive diagnosis was made at the end of follow up period (four small mass lesions at the macular area and two mass lesions out with the macular area).

In 18 cases (27%) no echographic cause was identified. Out of these, a definitive diagnosis was subsequently made on four cases (22%) (two cases of posterior vitreous detachment (PVD) and flat retinal breaks and two cases of haemorrhage in eyes with previously undiagnosed central retinal vein occlusion). The results are summarised in Table 2.

Table 1 Sound velocity in ocular and related media

Media	*Speed (m/s)*
Globe	1550
Globe (aphakic)	1532
Aqueous/vitreous	1532
Cornea	1620
Lens	1641
Dense cataract	1629
Sclera	1630
Silicone oil	986
PMMA	2718

Table 2 Vitreous haemorrhage, echographic diagnosis

Total number of cases	66 (100%)
Cause not identified	18 (27%)
Cause identified	48 (73%)
Diabetic retinopathy	19 (40%)
Age related maculopathy	9 (19%)
Retinal tear/detachment	7 (15%)
CRVO	4 (8%)
Terson's syndrome	3 (6%)
Identified but no definitive diagnosis	6 (12%)

Comment

The incidence and causes of vitreous haemorrhage in this study is in broad agreement with previous publications.[30 31] The results show that ultrasound is an accurate method of diagnosing vitreous haemorrhage, a conclusion reached by other workers.[31] This is important in cases where vitreous haemorrhage is suspected behind dense cataract, posterior synechia, etc. In the majority of cases (73%) an underlying pathology was identified on ultrasound. This indicates an important role for ultrasound; considering the clinical inability to carry out useful funduscopy in most of the cases. In all, 12% of the cases of identified pathology could not be definitively diagnosed, indicating the need for close observation and follow up in some cases. The results also show that although ultrasound is a good modality in detecting (elevated) retinal breaks and early detachment, it does not rule out the presence of flat retinal breaks. In cases when retinal breaks are suspected, serial ultrasound examinations are required to detect early development of retinal detachment or until media is sufficiently clear to allow funduscopy. Interestingly, ultrasound provided the referring clinician with further information, not previously recognised, and additional pathology (apart from VH) in many cases.

The conclusion of this study is that ultrasound is a useful modality in accurately diagnosing vitreous haemorrhage and in identifying an underlying cause in many cases. In some cases, however, a definitive diagnosis could not be established and (flat) retinal breaks could not be identified on echography. In such circumstances, serial ultrasound examination are required to detect further diagnostic features, rule out the development of retinal detachment, or allow time for vitreous haemorrhage to clear and funduscopy to be performed.

ULTRASOUND IN CLEAR MEDIA

In clear media, ultrasound plays a significant role in the differentiation of mass lesions. It is arguably the most accurate mean of tissue differentiation and measurements of raised intraocular tumours.[32 33] This is achieved by combining high resolution B-scan with standardised A-scan as described by Ossoining, Byrne, and Green. Coleman and co-workers have also produced results on the differentiation of melanoma with spectral analysis.[34] The presence of extrascleral extension of choroidal melanoma is a vital sign, not likely to be detected by any mean other than B-scan ultrasound. The echographic investigation of leucocoria is an essential component of the management of children with this condition and in the differentiation of its common causes.[35]

ORBITAL ULTRASOUND

Ultrasound is used as an imaging technique for screening of the orbit and differentiation of many of its lesions. Although inferior to computed tomography (CT) and magnetic resonance imaging (MRI) in depicting the bony wall, orbital apex, adjacent sinuses, and intracranial compartments, it is arguably a better imaging modality in

the detection of subtle changes in the soft tissues within the orbit and the differentiation of extraocular muscles and optic nerve lesions.[36] The unique kinetic property of ultrasound, including colour Doppler, gives it a distinct advantage in the diagnosis of vascular lesions and the assessment of normal and abnormal orbital circulation.[12 37] Additionally, its safety and relative low cost makes it an attractive "first line" imaging modality, and as a "screening method" before undertaking CT and MRI scanning.

New developments

One of the most significant advances in ophthalmic ultrasound in the last few years is the development of ultrasound biomicroscopy (UBM). Previously, the majority of clinical ultrasound instruments operated at a frequency between 1 and 10 MHz. A desire in ophthalmology to produce high resolution, magnified images of the anterior segment, and in other specialties such as dermatology for subsurface skin lesions, and vascular surgery for intravascular imaging has fuelled research into transducers' technology. Central to the progress in this field was the development of poly(vinylidene difluoride) (PVDF) transducers; capable of generating high frequency ultrasound in the range of 20–100 MHz. Other advantages of PVDF transducers include their low mechanical impedance and broad band properties. Sherar and colleagues pioneered the work on these transducers[38] and jointly with Pavlin development the first UBM apparatus for ophthalmic use in 1990.[13 14] Numerous publications have since emerged on the applications of UBM.[17] Other workers, notably Reinstein *et al* have since development their own prototype of high frequency ultrasound.[39]

UBM is clinically applied to investigate types of glaucoma, particularly those caused by, or associated with anatomical abnormalities—for example, narrow angle, plateau iris, iris dispersion, ciliary block, and aqueous misdirection glaucoma. UBM is an excellent imaging tool in differentiating solid versus cystic iris lesions and in the demonstration of ciliary body masses. Other noticeable applications include diseases of the cornea, sclera, and pars plana. Precise identification of IOL position (and its haptic) and anteriorly located intraocular foreign bodies is now possible with UBM. Owing to its high frequency, however, UBM does not penetrate beyond 5 mm from the ocular surface, and therefore will not replace conventional ultrasound in imaging of the posterior segment and orbit.

Other promising new developments in the field of diagnostic ultrasound that are not yet fully tested in ophthalmology include power Doppler and echo contrast agents.

Power Doppler (PD) is a new modification of Doppler ultrasound that displays the strength of the Doppler signal, rather than velocity and directional information normally obtained from colour Doppler (CD).[40 41] PD has three times the sensitivity of conventional CD in detecting blood flow. It is also capable of visualising much smaller vascular architecture as compared with CD and detecting relative areas of ischaemia and hyperaemia. It is therefore potentially useful in imaging of vascular lesions of the globe and orbit, and early studies in the orbit have shown that PD is superior to CD in the detection of flow in the ophthalmic artery and vein, and also in the retinal artery and vein.[42 43]

Echo contrast agents are now a well established adjunct in cardiac sonography.[44] The most common agent is agitated gas microbubbles. More recent agents, with longer circulation life, include galactose microbubbles (Echovist and Levovist).[45] These contrast agents act by increasing the backscatter effect of ultrasound in vascular regions. They can be used with B-scan and Doppler ultrasound, and by using "harmonic imaging" it is possible to image the contrast agent maximally while inhibiting artefacts from surrounding tissue; a process similar to that employed in digital subtraction angiography. The application of echo contrast agents in ophthalmology has not been fully tested but may prove useful in imaging of small vessels and vascular lesions.

Other promising developments in ultrasound in general include three dimensional imaging,[46 47] refinement in transducer's material and technology, leading to improvements in sensitivity and bandwidth.[48]

All these features, in addition to the inherent safety of ultrasound, will ensure its viability as an imaging modality for many years to come and into the new millennium.

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