The assessment of ocular injury by ultrasound

J.A. Fielding*

Radiology Department, Royal Shrewsbury Hospital NHS Trust, Shrewsbury, UK

Received 10 July 2003; received in revised form 3 October 2003; accepted 9 October 2003

KEYWORDS
Eye; Injuries; Ultrasound

Introduction

Examination of the intra-ocular contents by ophthalmoscopy is dependent upon transparent light-conducting media: the cornea, the aqueous humour, the lens and vitreous gel. After trauma, the media are frequently opacified by haemorrhage, laceration, scarring or cataract. Internal injury is often more serious than is immediately apparent, and contusional damage to posterior segment structures carries an unfavourable visual prognosis.1 The aim of surgery is to intervene at an early stage, so that vitrectomy and other microsurgical techniques are carried out before chronic, irreversible, changes develop which threaten the patient’s sight.2 The results of vitreous surgery in posterior segment trauma support the concept of early secondary intra-ocular reconstruction, surgery undertaken before development of retinal detachment, which improves the prognosis for visual recovery.3 Vitrectomy, with severance of adhesions, is carried out by inserting microsurgical instruments through the pars plana. A suction-cutter shears off pieces of the vitreous, which are aspirated by the pump, while positive pressure is maintained by infusion. The indications for vitrectomy are dense and persistent vitreous haemorrhage, the formation of vitreous membranes, vitreo-retinal adhesions and tractional retinal detachment, particularly if progressing to involve the macula.4 6

Before surgery, it is helpful to have knowledge of the degree of internal derangement, and in the presence of opaque media, ultrasound has proved the ideal tool. Information is provided about vitreous haemorrhage, lens dislocation and rupture, detachment of the coats, globe rupture and foreign bodies. Ophthalmic ultrasonography has often been the province of ophthalmologists using dedicated equipment. However, due to the excellent quality of high-resolution images produced by currently available general purpose scanners with small parts probes, ocular ultrasound is within the scope of the interested radiologist. At energy levels used for diagnostic purposes, no known adverse effects have been demonstrated.7 Although many surgeons consider it advantageous to perform the ultrasound examination as an adjunct to clinical examination, thus having first-hand insight into intra-ocular structures and dynamics before operation, others rely on a radiologist or other trained operator.

The eye is the prominent organ in the anterior orbit, its cystic structure and superficial position making it ideal for ultrasound examination (Fig. 1). Although computed tomography (CT) and magnetic resonance imaging (MRI) are invaluable in many orbital conditions, they lack the immediacy and

*Guarantor and correspondent: J.A. Fielding, Radiology Department, Royal Shrewsbury Hospital NHS Trust, Mytton Oak Road, Shrewsbury SY3 8XQ, UK. Tel: +44-1743-261000, x3279; fax: +44-1743-261439.
E-mail address: jafielding@doctors.org.uk
simplicity of ultrasound, cannot produce real-time images, and have considerable limitations when imaging the vitreous and retina, whereas ultrasound contributes more to tissue diagnosis.

Dynamic examination is important, and with increasing experience the examiner is able to study characteristics of the motion and topography of pathological intra-ocular conditions, enabling identification of detachment of the coats, vitreous membranes and vitreo-retinal adhesions.

To interpret images of the pathological eye it is vital to have a clear understanding of the anatomy and points of firm attachment of the vitreous, retina and choroid (Fig. 2).

Patients and methods

The images included in this review are from patients with opaque media after ocular trauma, referred by ophthalmologists in the county of Shropshire. All examinations were carried out by the author over the last decade. Through-the-lid contact imaging was employed with a standard, water-soluble coupling gel, using a very gentle technique to cause minimal discomfort to the injured eye. Children tolerate the examination well. With open wounds, a sterile sheath is placed over the probe, or a 3 mm sterile gel pad is used to cover the eyelid. The images demonstrated are from high-resolution ultrasound machines using small parts probes of frequencies between 10-12 MHz. Sector or linear scanning is carried out with the patient lying supine, in which position the head is supported, making it easier to remain still. Gravitational pull is exerted in the direction of the optic axis, enabling a detached vitreous still suspended from the vitreous base, or sedimentation of blood to be readily assessed. Each eye is imaged while static and, if possible, during eye movements with the patient deviating the eyes to the right and left side, during which pathological structures are observed, such as vitreo-retinal adhesions, detachments and membranes. Characteristics of the type of mobility of these structures help identification and diagnosis, the vitreous gel moving as a complete body, but the detached retina undulating as a membrane. Movement is not possible with some injured eyes, limiting the examination and making diagnosis less straightforward. Complete visualization of the ocular contents is achieved by transverse and longitudinal imaging, and angulation of the transducer.

Ultrasound has a limited role in the detection of foreign bodies, secondary to plain films and CT with 3 mm contiguous sections in axial and coronal planes through the orbit, supplemented by coronal and sagittal reconstructions when necessary. When globe rupture is sought, 2 mm axial and coronal high-resolution CT is carried out in addition to ultrasound.

Types of injury

There are two main types of ocular injury which render the media opaque to ophthalmoscopy: blunt and penetrating, although both may occur simultaneously.

Blunt injuries

These characteristically cause a spectrum of damage, involving multiple intra-ocular structures,
due to compression of the anteroposterior (AP) diameter of the eye and corresponding expansion of the equatorial plane. Differential elasticity of the vitreous causes traction at the posterior part of the vitreous base, with retinal tearing (dialysis). Severe, blunt injury may cause extensive intraocular haemorrhage, retinal tearing and scleral rupture (Figs. 3–5).

Anterior chamber

Hyphema, itself a cause of media opacification is readily identified on ultrasound (Fig. 6). The advent of high-resolution, linear array probes has lessened the problem of “near-field” artefact, but if the latter is present, a stand off gel is helpful. The ultrasound biomicroscope, employing frequencies of 50-100 MHz has been used in some centres to image abnormalities of the anterior segment, such as corneal oedema, the depth of the chamber, the state of the angle and the position of the lens.10

Lens dislocation or disruption

Posterior dislocation (Fig. 7) and occasionally anterior or lateral dislocation is seen. The dislocated lens or its nucleus is seen as the normal oval shape, and is usually mobile with eye movements. It is more readily identified if a cataract has formed. If rupture of the posterior lens capsule occurs with extrusion of lens material into the anterior vitreous, the lens material is less easy to identify. Lens dislocation resulting from injury is relatively common, a series of 71 consecutive cases of ocular trauma containing 12 displacements.11 Posterior dislocation produces few immediate complications, but if surgery is required (e.g. with the onset of lens-induced uveitis) vitrectomy techniques are undertaken.

Vitreous haemorrhage

This hampers examination by direct vision. During the first 24 h after vitreous haemorrhage, only a few low-amplitude reflections are seen, reflectivity increasing markedly over the next few days.11 Ultrasound is very sensitive for the detection of vitreous haemorrhage and even small bleeds can be
identified as scattered reflections in the vitreous cavity. With some penetrating injuries, a track of haemorrhage is identified, outlining the route of passage of a foreign body (Fig. 8). The vitreous is firmly attached anteriorly at the pars plana and ciliary processes, less firmly at the optic disc, and elsewhere lies in free contact with the retina. Detachment therefore takes place posteriorly.

Eyes with opacified media are examined to determine the severity and extent of vitreous haemorrhage, and any coexistent abnormalities, for example retinal tear, retinal detachment or choroidal detachment (Fig. 9). Dense vitreous haemorrhage obscuring fundus details carries a guarded prognosis. Identification of other latent injuries is not easy if vitreous haemorrhage is severe, because of the juxtaposition of reflective blood and detached coats. Uncomplicated vitreous haemorrhages are followed up at 4 week intervals to check for clearing (reduction in vitreous opacities) or for membrane formation, (Fig. 10), or the development of retinal detachment (Fig. 11) which requires surgery. Mobile linear opacities and fibrous membranes within the gel have been termed "arranged" rather than "organized", the latter term implying fibrovascular invasion, which occurs rarely in uncomplicated vitreous haemorrhage.8

In animal experiments vitreous haemorrhage has been shown to remain as a discrete blood clot for about 4-6 weeks, after which it reduces in size.12 The presence of blood exerts severe destructive
effects on gel structure; including posterior vitreous detachment, liquefaction of the gel, the formation of fibrinous vitreous membranes and the formation of a pseudocapsule around the clot. Small haemorrhages can remain unresolved for several weeks. No fibrosis occurred in the rabbit vitreous, even with longstanding residual blood deposits, and it has been suggested that fibrosis (with tractional retinal detachment) is an unusual sequel to uncomplicated vitreous haemorrhage, the former occurring in ocular diseases in which vitreous haemorrhage may be an incidental occurrence (e.g. ocular trauma, diabetic retinopathy). Experimentally, vitreous fibrosis followed a traumatic injection procedure involving perforation of the retinal layers, and sometimes occurred with an associated retinal detachment. The retinal tears associated with trauma are thought to be the catalyst for development of vitreous and retinal fibrosis.

**Fibrinous vitreous membrane**

It is important to document the development of membranes in persistent vitreous haemorrhage, especially with vitreo-retinal adhesions, which may require vitrectomy. The fibrinous membranes are initially very mobile on dynamic imaging, but become less so with the passage of time. They may mimic retinal detachments, and particular care must be taken when examining to differentiate these conditions. Fibrinous membranes are usually finer than a detached retina, and move with the vitreous gel on dynamic imaging, lacking the firm anatomical attachments of the retina. An ochre membrane may be formed by sedimentation of erythrocytes on the vitreous surface (Fig. 12), also requiring care to differentiate from retinal detachment. Vitreous membranes have a lower reflectivity than the detached retina, and are more mobile, usually without attachment to the optic disc.

Some ophthalmologists use quantitative A-scanning to differentiate between vitreous membrane and retinal detachment, especially if the membrane does attach at the optic disc. Standardized A scanning is a method developed by Ossoinig, quantifying the differing reflectivity of intra-ocular structures compared with scleral reflectivity. Nevertheless, the usefulness of the A scan is undermined by the overlap zone, as some thick membranes are more reflective than the detached retina, and an atrophic retina may be less reflective than a membrane. Some workers therefore no longer use the A scan for diagnostic purposes.

**Retinal tears**

Retinal tearing is a precursor of retinal detachment,
and the majority of tears or breaks are caused by blunt injuries occurring at the time of impact. Tears are typically situated at areas of maximum scleral displacement, either in the region of the vitreous base or at the point of impact. Cooling\(^1\) in 1987 stated that the vitreous base is avulsed in approximately 25% of all cases of contusion detachment. Visualization of breaks or tears by ophthalmoscopy is frequently hampered by intra-ocular haemorrhage. They are also difficult to see on ultrasound unless substantial, and appear as short, reflective, linear structures, projecting into the vitreous cavity with an abrupt termination (Fig. 13). They are easier to demonstrate when there is less intra-ocular disruption and when not surrounded by dense vitreous haemorrhage. Penetrating injuries may cause tears, for example a piercing injury from a sharp object (Fig. 14).

**Retinal detachment**

The aim of scanning soon after injury is either to identify retinal detachment that has already occurred, so that treatment may be instituted, or to carry out follow-up ultrasound in severe vitreous haemorrhage to ensure retinal detachment does not develop. Retinal detachment is readily diagnosed on ultrasound, the complete detachment appearing as a “V” shape in the vitreous cavity due to the retina maintaining firm anatomical attachments anteriorly at the ora serrata and posteriorly at the optic nerve head (Fig. 15). Normally, a clear zone is seen between the retinal detachment and the coats, but with subretinal haemorrhage, reflective fluid is seen in this compartment. Partial detachment shows as a linear membrane, usually extending to the optic nerve head, but not across it as with vitreous membranes. Recent detachments have an undulating type of mobility on dynamic scanning, but more longstanding detachments display a “flapping” type of motion in the early stages of proliferative vitreo-retinopathy, before progressing to the rigid “triangle sign”. The appearances of tractional retinal detachment due to development of fibrous membranes are described later.

Sometimes an unpredictable latent interval occurs between injury and the development of retinal detachment, the latter being delayed and slowly progressive. This is because the majority of injuries occur in young people with healthy gels that do not readily detach and lose volume, thus
providing support for the retina. Most retinal detachments caused by blunt injury are managed by standard repair techniques with cryotherapy and explants to support the anterior retina. Vitreous opacities, giant tears and posterior tears are treated by vitrectomy and gas tamponade.

**Choroidal injury**

Choroidal tears, haemorrhage and detachment (choroidal detachment) result from severe blunt injury. The diagnosis is readily made with ultrasound, the detached choroid showing as a convex indentation into the vitreous cavity, due to the choroid maintaining firm anatomical attachments anteriorly at the scleral spur and posteriorly at the exit foramina of the vortex veins (Fig. 16). Complete choroidal detachment indicates a poor prognosis, and if associated with vitreous haemorrhage and suprachoroidal haemorrhage, the reflective blood renders the imaging of detached coats either difficult or impossible.

The diagnosis of incomplete choroidal detachment is sometimes useful in alerting the surgeon to the possibility that his instruments may enter the suprachoroidal space rather than the vitreous cavity. Choroiditis with choroidal thickening sometimes occurs in eyes after perforating wounds (Fig. 17). This complication is tenacious and persistent, heralding the onset of ocular atrophy. It has also been reported occurring transiently in eyes after surgery.\(^{18}\) Clinically the eye shows a low-grade inflammation, with choroidal thickening and oedema of the optic disc and macula. On ultrasound, the choroid is swollen, and may be measured by the electronic callipers, demonstrating an increase above the normal 1 mm thickness.

**Globe rupture**

Eyes clinically suspected of rupture are examined with an extremely gentle technique during ultrasound examinations, to prevent expulsion of ocular contents. Blows to the antero-lateral aspect of the eye, which is relatively unprotected by the orbital walls, have a higher frequency of globe rupture. Compression of the AP diameter of the globe results in corresponding expansion of the equatorial plane, with equatorial scleral rupture. Ultrasound findings are distortion of the normal global shape with loss of ocular volume, intra-vitreal haemorrhage and
scleral discontinuity (Fig. 18). The latter is not easy to identify, and is more readily confirmed by CT (Figs. 4 and 5), when 2 mm axial high-resolution CT is carried out, followed by sagittal and coronal reconstructions if the diagnosis is not made in axial examinations (Fig. 19).

Clinically, intra-ocular pressure measurements by tonometry are an indication of rupture but are not always accurate. Using imaging to identify and confirm the scleral rupture is useful for surgical planning, in difficult cases. Ruptures extending posterior to rectus muscle insertions have a poor prognosis, with the development of expulsive choroidal haemorrhage or retinal prolapse.

**Penetrating injuries**

Penetrating injuries cause a wide spectrum of damage, and ultrasound helps to determine the extent and severity of initial structural disruption; particularly vitreous haemorrhage, vitreous incarceration, posterior vitreous detachment, vitreo-retinal adhesion and retinal tears (Fig. 8). Penetrating injuries are frequently caused by the passage of foreign bodies, or piercing by sharp objects, some resulting in double penetration of the globe with major contusional damage and poor visual outcome.

**Foreign bodies**

High-velocity foreign bodies result in double penetration of the globe; entry and exit points often causing severe contusion, vitreous laceration and impaction. Vitreous incarceration is carefully sought after penetrating injury (Fig. 20), because of the high risk of development of vitreous membranes and tractional retinal detachment, unless pre-empted by early surgical intervention, with vitrectomy and severance of vitreo-retinal adhesions.

Ultrasound has a limited role in the detection of orbital foreign bodies, because a large proportion of retrobulbar tissue is highly reflective fat. Many foreign bodies are also reflective and easily lost in the orbital “white-out”.[19] Clinical management of foreign bodies is dependent on the composition and site. Intra-ocular foreign bodies are usually removed surgically (Fig. 21), to prevent complications from chemical reactions (e.g. siderosis from iron) or infection. Extra-ocular foreign bodies are managed conservatively, and it is therefore important to accurately differentiate between intra-ocular and extra-ocular locations. This is readily achieved by CT (Fig. 22), although ultrasonography is superior in the assessment of intra-ocular...
soft-tissue damage. However, ultrasound is less sensitive than CT in the demonstration of foreign bodies in the globe.\textsuperscript{20,21} It has been stated that CT is the investigation of choice, following plain radiography in cases of suspected ocular injury.\textsuperscript{22,23} Nevertheless, CT is unable to resolve subtle intraocular soft-tissue damage\textsuperscript{24} such as vitreo-retinal impaction or adhesion (Fig. 20), and the examination cannot be carried out in real-time, which is necessary for identification of these features. CT must always be used judiciously, as high-resolution CT delivers a significant dose of radiation to the orbital contents, particularly the lens.\textsuperscript{25} The most useful sequence of investigation of orbital foreign body is therefore, plain films (to confirm the presence of a foreign body and identify others), CT to localize the foreign body, then ultrasound to determine associated intra-ocular injury.

Some investigators recommend MRI in suspected wooden foreign body in the orbit, if no foreign body has been defined on plain films, ultrasound or CT. Green et al.\textsuperscript{26} described two patients where these initial examinations showed no evidence of a foreign body, but subsequent MRI delineated a wooden orbital foreign body in each case. Hydrated and dry wooden foreign bodies exhibit differing CT and MRI characteristics, due to varying water content.\textsuperscript{9,27,28}

There is a theoretical risk of orbital or ocular damage when imaging foreign bodies made of ferrous metal with MRI. However, in a study involving insertion of both ferrous and non-ferrous metals foreign bodies in bovine eyes, Williamson et al.\textsuperscript{29} accurately located the foreign bodies with MRI, and subsequent dissection revealed no ocular damage attributable to movement of the foreign bodies in the magnetic field. It has been stated that the risk of eye damage is low for patients with intraorbital metal,\textsuperscript{30} a position refuted by others.\textsuperscript{31} Nevertheless, MRI is not always readily available and is still a costly investigation compared with the other imaging methods.

**Vitreous incarceration**

This is an important complication of penetrating injury. At the site of penetration, the vitreous becomes impacted into the retina, forming a vitreo-retinal adhesion (Fig. 20). The retina is breached, initiating the development of fibroplastic (rather than fibrinous) vitreous membranes, which, if not treated early, later contract to form a tractional retinal detachment.\textsuperscript{13} Vitreous incarceration is inferred if ultrasound demonstrates asymmetric suspension of the gel or impaction at the site of
penetration through the coats, at the termination of a laceration or haemorrhage track. The route traversed by a foreign body (usually at high velocity) must be carefully sought, as widely differing appearances are found in different sections through the globe.

Proliferative vitreoretinopathy and traction retinal detachment

Blunt injuries resulting in retinal tearing and penetrating injuries causing retinal holes both risk development of rhegmatogenous retinal detachment (i.e. with a break or hole). If left untreated there is a proliferation of fibroplastic membranes on surfaces of the detached retina, and on the posterior surface of the detached gel. Ultrasound shows the shortened, rigid retinal surfaces with a transvitreal membrane forming the "triangle sign" (Fig. 23). Dynamic imaging gives a vivid demonstration of the fixity of these structures. Advanced proliferative vitreo-retinopathy is a difficult surgical prospect, contraction of the fibrotic membranes with further retinal elevation being the most important cause of failure, in retinal reattachment surgery. The many differing surgical techniques are an indication of generally unsatisfactory results.

At the opposite end of the spectrum, certain early post-traumatic changes also give "V"-shaped appearances on ultrasound, with entirely different characteristics and prognosis (Fig. 24). Shallow tractional retinal detachment is caused by vitreo-retinal adhesion, dynamic imaging showing great mobility of the collapsed vitreous. If left untreated, a full-blown tractional retinal detachment develops (Fig. 25), an occurrence prevented by early intervention by vitrectomy.

Intra-ocular air

The presence of intra-ocular air is a pitfall for the
un wary when interpreting the ultrasound findings after a penetrating injury. The tissue-air boundary is highly reflective and a small air bubble appears on ultrasound as a dense, reflective body in the vitreous, thus mimicking or masking a metallic foreign body. If the head is tilted an air bubble will float in the opposite direction, but this is not always easy to demonstrate (Fig. 26). However, air pockets are clearly shown by CT if an immediate ultrasound examination. The pitfall of misdiagnosing intra-vitreal air. With foreign bodies, adherence to the correct investigative sequence of plain films, CT then ultrasound, ensures that the radiologist is alerted to the presence of intra-ocular air before the ultrasound examination.

Conclusion

Ultrasound is a gentle, non-invasive and rapid way of assessing intra-ocular damage caused by blunt and penetrating trauma, when the media have been rendered opaque to ophthalmoscopy. The images provide essential, detailed information about soft-tissue damage, aiding decisions regarding early surgery, before chronic changes have occurred. In the investigation of foreign bodies and associated intra-ocular injuries, the sequence of plain films, CT, then ultrasound (followed by MRI if a wooden foreign body is still suspected) provides a logical method of examination, ensuring detection of ocular and orbital foreign bodies and intra-ocular damage, whilst helping the unwary to avoid the pitfall of misdiagnosing intra-vitreal air.

References


