A REVIEW OF THE GROOTE SCHUUR HOSPITAL EXPERIENCE OF LOW-VELOCITY NON-MISSILE PENETRATING ORBITAL AND TRANSORBITAL STAB WOUNDS

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DECLARATION

I, Christopher John Welman, hereby declare that the work on which this dissertation is based, is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it is being or is to be submitted for a degree at any other university.

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TABLE OF CONTENTS

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ABBREVIATIONS

ACA Anterior cerebral artery
ACF Anterior cranial fossa
APD Afferent pupillary defect
CCA Common carotid artery
CCF Carotico-cavernous fistula
CF Counts fingers (visual acuity measurement)
CSF Cerebrospinal fluid
CT Computed tomography
ECA External carotid artery
EDH Extradural haemorrhage
GCS Glasgow Coma Scale
GWS Greater wing of the sphenoid bone
HM Hand movement seen (visual acuity measurement)
ICA Internal carotid artery
ICH Intracerebral haemorrhage
IJV Internal jugular vein
IVH Intraventricular haemorrhage
L Left
MCA Middle cerebral artery
MCF Middle cranial fossa
MRI Magnetic resonance imaging
NPL No perception of light (visual acuity measurement)
PCA Posterior cerebral artery
PL Perception of light (visual acuity measurement)
R Right
RAPD Relative afferent pupillary defect
SAH Subarachnoid haemorrhage
SDH Subdural haemorrhage
SOV Superior ophthalmic vein

SXR Skull x-ray

TAPD Total afferent pupillary defect

VA Visual acuity (as measured with a Snellen's Chart)

LIST OF TABLES AND GRAPHS

REVIEW OF THE LITERATURE

Introduction and definitions

Penetrating orbital trauma in this dissertation refers to any injury caused by a low-velocity, sharp (i.e. small impact area) object that traverses or is suspected to have traversed the orbital space. In order for the object to traverse the orbit, the portion of the object behind the tip also generally needs to be thin. The point of entry may be the anterior surface of the eye, or any of the orbital walls. Low velocity sharp objects include hand-held objects (often used as weapons) or stationary sharp objects against which the person falls or is forced against. This excludes missile injuries from gunshot wounds and shrapnel. Sharp injuries where the force is dissipated over a long zone of contact viz. panga (cane-knife) or axe, are more akin to blunt injuries and are excluded. Also excluded are impalement injuries where the patient was moving at high speed. Although often visually devastating, superficial lacerations of the anterior globe, usually from a broken glass bottle, are also excluded. This selective definition is supported by many authors. The anatomical structure of the orbit, the nature of the trauma i.e. low-velocity stab with a sharp object and the often minor external wound, with late onset of serious complications, supports the opinion that low-velocity penetrating orbital trauma should be regarded as a special category.[1, 2(pp12-14)]

Literature overview

The most comprehensive review on the subject to date is the book by van Duinen published 2000. He collated a total of 360 publications describing 347 cases. These include articles written as far back as 1818, German and French dissertations written in 1904 and 1905 respectively and several other foreign language publications.[2] Unfortunately a few transoral and transnasal injuries are included in the data and the book lacks uniformity in its handling of the subject. Many of the percentages in van Duinen's review are quoted without the supporting raw data, and are therefore reproduced as such in this dissertation. On the whole however, it provides an excellent resource for the minutiae contained in practically unobtainable publications.[3] There have been several additional case reports that were not recorded in van Duinen's book, or have been published since his review was published.[4-14] Amongst all these publications, the largest single series of transorbital stabs due to intentional trauma i.e. assault, and the largest involving knives was reported from the Departments of Neurosurgery and Ophthalmology at Groote Schuur Hospital in 1975. They initially described 10 cases of transorbital stab wounds that resulted in intracranial complications.[15, 16] De Villiers added 6 cases to the previous series and presented them to The Society of British Neurological Surgeons in 1975.[17] Kieck and De Villiers described a further 20 cases of orbital stab wounds as a subset of 109 patients who had suffered a vascular lesion as a result of transcranial stab wounds.[18]

Incidence and historical perspective

Penetrating trauma to the eye was more common before the 19th century, when daggers or swords were often carried for self-defence and used as the primary weapon during staged conflicts between massed armies. Numerous accounts exist of various people, including royalty e.g. King Henry II of France, succumbing from orbital penetrating wounds.[2(pp7-11), 16] The earliest Biblical account is probably the blinding of Samson (Judges 16:21), an event vividly depicted in a Rembrandt oil painting.[19]

Although a rare injury, the incidence of trauma to the orbit nowadays is frequently influenced by social, economic and cultural factors. In most first-world settings, the injury is accidental. Intentional trauma occurs where there is a high incidence of interpersonal violence, such as in South Africa.[20]

Anatomical factors

The orbit is pyramidal in shape, with an anterolateral quadrangular base situated at the orbital margin. The orbital roof is comprised of the orbital process of the frontal bone and the lesser wing of the sphenoid bone. It separates the orbital contents from the frontal lobe. The medial wall of the orbit comprises the ethmoid bone, the body of the sphenoid bone, the lacrimal bone and the frontal process of the maxillary bone. This paper-thin bone wall (lamina papyraceae) separates the orbital contents from the ethmoid sinus. The orbital floor is comprised of the orbital process of the zygomatic bone, maxillary bone and part of the palatine bone; this separates the orbital contents from the maxillary sinus. The lateral orbital wall is comprised of the orbital process of the greater wing of sphenoid, zygomatic bone and the orbital process of the frontal bone. It is the thickest orbital wall and is not bordered by a paranasal sinus. The four orbital walls converge towards the posteromedially situated orbital apex. The orbital apex comprises the optic canal and superior orbital fissure. The optic canal is bounded by the components of the lesser wing of sphenoid bone and transmits the optic nerve and ophthalmic artery. The superior orbital fissure, situated lateral to the optic canal is formed from the greater and lesser wings of the sphenoid bone. The superior and inferior ophthalmic veins, as well as the 3rd, 4th and 6th cranial nerves pass through the superior orbital fissure. The inferior orbital fissure situated in the inferolateral portion of the posterior orbit is bounded by the lesser wing of the sphenoid bone, palatine bone, maxillary bone and zygomatic bone.[21]

The orbit allows sharp pointed objects easy access to the brain via the superior orbital fissure, optic foramen or orbital roof; the latter especially in children. Depending on the length and direction of the penetration, almost any part of the brain can be reached in cadavers.[2(pp15-19)] Injury may occur to the globe; the orbital arteries and veins; the 2nd, 3rd, 4th and 6th cranial nerves; and the extraocular muscles. The greater wing of sphenoid may direct the blade medially towards the orbital apex. Damage may occur to the cavernous sinus and the intracranial internal carotid artery if the knife penetrates the orbital apex. A knife passing through the superior orbital fissure may damage the temporal lobe. Children are particularly prone to carried objects penetrating the orbital roof and extending into the frontal lobe.[15, 16] As the lateral wall of the orbit is the thickest of the orbital walls and is aligned at 45° to the sagittal plane, a knife may follow this wall and damage the contralateral optic nerve, carotid artery, cavernous sinus and frontal or temporal lobes.[15, 16, 22-25]

Demographics

In a collated series of 315 cases with recorded ages, half of all those injured were younger than 16 years of age, and the highest incidence occurred between 1 and 13 years of age. This was felt to reflect the high incidence of accidental trauma in children who fall onto a sharp object carried in their hands.[2(pp23-25, 96-102)] Although intentional trauma often occurs in young males,[1, 15, 16, 18] only 24% (84/347) cases reported by van Duinen were due to aggression. Males were injured 4 times more frequently than females; of the 84 cases due to assault, 89% were males and 11% females.[2(pp24-25, 91-93)]

Even in cases without transorbital intracranial entry, penetrating eye injuries are commoner in males (80%) and often associated with alcohol (25%) and illicit drug (10%) use. The median age of patients that fell onto a recreational object was 5 years of age. A domestic fall onto a household object had a median age of 66 years of age.[26]

Mechanism of injury

In the collated series of 347 cases by van Duinen, 38% were due to falls, 33% due to accidents, 24% due to aggression, 2% due to attempted suicides and 3% unknown.[2(p26)] This review excluded some cases that were due to intentional assault [1, 5, 10, 11, 14, 27-31] and some that were accidental.[32]

Historically, the deliberate surgical penetration of the superior orbital roof to perform a prefrontal leucotomy was first described in the mid-20th century.[33, 34] Moore et al described 2 deaths in their series of 102 patients who underwent transorbital leucotomy.[33]

Instrument

In the total series of 347 cases recorded by van Duinen, the commonest objects involved were sticks (77), pencils (52), metal rods (49), umbrella tips (40), knives (33), pitchforks (17) and chopsticks (10). Numerous other items as varied as toothbrushes and a kangaroo tooth have also been described.[2(pp20-22), 35] The knife and umbrella were the objects most frequently used in assault in 33% of cases. The mortality from umbrella stabs was four times higher than those due to a knife stabs.[2(pp91, 103-104)] In one large series of cranial stabs, 48% of patients did not know what object caused the stab.[1]

Site and side of injury

Although the site of entry may be anywhere around the orbit, most penetrating injuries enter the orbit through the soft anterior portion. Of stabs to the head, the orbit was the 2nd commonest site for a stab, after the parietal region.[1] Accidental injuries tend to occur equally in both eyes, although in one series of 347 cases the right orbit was more often involved than the left (right 50%, left 43%, unknown 7%).[2(p25)] This, however, varied considerably when the cause for the injury was taken into account. In the 84 cases due to aggression, 70.5% were on the left and 29.5% on the right.[2(p91)] De Villiers and Sevel found in their series that orbital stabs occurred with almost equal frequency on the left or right side (six on left and four on the right).[15, 16] Another series recorded 165 left-sided stabs versus 84 right-sided stabs to the head.[1] As most assailants are expected to be right-handed, when facing their victims assault injuries should usually involve the left orbit.[36] Again, as most people are right-handed, most suicidal cases involve the ipsilateral (right) eye. Even in suicidal cases that have initially attempted to stab the contralateral eye, successful penetration ultimately occurs in the ipsilateral eye.[10, 37] Injuries that result from a fall onto an object held in the dominant hand are also more likely to involve the right eye.[2(p94)]

The predominant site for injury within the orbit is the upper medial portion of the orbit. Injury to the upper lid occurred in 45% of 284 cases, with the ratio of medial to lateral of 3:1.[2(p94)]

Mortality

In the early literature, an almost 100% mortality followed this injury. In the period from 1977 to 1997, van Duinen reported 129 cases with a 13% mortality.[2(p114)] There are no data available to determine the number of people who die prior to reaching medical attention. Although referring to wartime high-velocity injuries, Webster et al reported 12.5% mortality from penetrating orbitocranial injuries versus half that (6.4%) for penetrating cranial injuries not involving the orbit.[38] Birch-Hirschfeld collected 169 cases from the literature and added 3 cases of his own, and found that of these, 20 died (11 due to meningitis, 6 due to internal carotid artery injury and 3 due to tetanus), while 125 suffered optic nerve injury.[39] This German-language publication is not obtainable but has been cited by several independent sources.[40-42] Three of 10 in the series with intracranial complications reported by de Villiers and Sevel died.[15, 16] Of note in this series is the observation that all those that died experienced gross disorganisation of the globe. In the expanded series, 5 of 16 patients died. Causes included one carotid artery thrombosis and 4 massive intracerebral haemorrhages.[17]

In the series by van Duinen, the overall mortality from injury due to assault was 44% (37/84), compared with 24% (31/130) for the fall related group and 22% (25/114) for the accidental injury group.[2(pp92, 94, 101)] An injury due to assault was found more likely to have a medial and horizontal direction and penetrate the posterior orbital roof, whereas an injury due to a fall was more likely to penetrate the anterior frontal lobe. While penetration via the posterior orbit, near to the cavernous sinus and internal carotid arteries, might be expected to have a higher mortality and morbidity, this is not supported by the finding that penetration via the superior orbital fissure (SOF) and orbital roof had mortalities of 15% (13/89) and 33% (49/149) respectively.[2(pp. 41, 43, 114)] Mortality was also 4 times higher following umbrella (20/28) versus knife (5/28) stabs.[2(pp91, 103-104)]

In those victims where the knife was removed by the assailant, the outcome was worse than those with a retained knife at presentation. This difference was thought to be the result of added injury due to side-to-side movement during extraction of the blade.[43]

Another described mechanism of death is the oculocardiac (or trigeminocardiac or blepharocardiac) reflex, which can cause cardiac arrhythmias (including ventricular tachycardia and asystole) after stimulation of the globe by direct pressure, orbital haematoma, intraocular injection or severe injury to the orbit.[27]

Pathology

Low-velocity (e.g. stab) wounds to the brain differ from high-velocity (e.g. gunshot) wounds. Apart from direct lacerations of vital structures, stab wounds develop a limited area of haemorrhage and necrosis around the injury tract. Gunshots have extensive surrounding necrosis due to the high kinetic and cavitating forces arising from the penetrating missile.[44, 45]

Clinical presentation

There is a wide range of clinical presentations. Rapid death may result from massive intracranial haemorrhage. Early presentation may be as a known stab wound, without or with a focal neurological deficit and/or depressed level of consciousness, or disruption of the outer skull table only identified during cleaning of a scalp wound. Delayed presentations include infective complications or carotico-cavernous fistulae. The latter will usually present with pulsatile proptosis and bruit.[16, 36] Proptosis however may also follow haemorrhage within the orbit.[15, 16]

Some stab wounds may be clinically occult, such as in the fornix of the conjunctiva.[46, 47] Chemosis or subconjunctival haemorrhage may mask the entrance wound. For this reason, any wound in the vicinity of the orbit should be viewed with suspicion.[40] In the series reported by van Duinen, 14% did not have an eyelid injury; penetration must thus have occurred via the conjunctiva. In 49%, only a small (less than 1cm) wound was found; in 16%, it was larger. The size was not recorded in 20% of cases, although a stab was present.[2(p48)]

Even though most injuries present within hours of the injury, a carotico-cavernous fistula typically has a delayed presentation – sometimes up to 2 years later.[15, 16, 36] In the series reported by van Duinen, 16% of cases presented within the first 24 hours, 41% presented between 1 and 14 days, 21.6% within 2 to 8 weeks, 10.3% in 2 to 8 months and 11.1% at 5 to 30 years.[2(p49)]

The findings on physical examination are varied, and depend on the site of entry and track of the object. A full ophthalmological and neurological examination should be carried out on admission and repeated frequently. It has been suggested that a low-velocity, thin object can displace the globe without causing disruption.[23, 48] In van

Duinen's series, 74% of globes were intact.[2(p53)] A large, broad blade is however certain to cause injury to the globe.[15, 16]

Contralateral injuries to the neurovascular structures opposite to the stab site should be sought.[2(p46), 24, 49]

An interesting vascular mechanism has been proposed for a single case of a retained knife in the right infraorbital margin with a left (contralateral) inferonasal field defect. It was speculated that this was due to damage to the lateral chiasmal artery. This is a single nutrient artery supplying the superotemporal part of the intracranial optic nerve.[28]

Retained Blades and Foreign Bodies

Not infrequently, the penetrating object breaks off or becomes lodged in the orbital region. In the series by van Duinen, 25% of cases had the penetrating object in-situ at presentation, in 44% the object had been removed, in 22% there were intraorbital and/or intracranial fragments while no details were available in 9%.[2(p49)] This is a high risk subgroup of patients. It is postulated that a retained blade indicates that the blade is more likely to have penetrated deeper into the brain and exposed more vessels to possible injury. Retained blades may also tamponade injured vessels, and the patient may then deteriorate following removal of the knife. In the series reported by Taylor and Peter, this situation occurred in 3 patients, 2 of whom died, of a group of 13 patients with retained cranial knife blades at presentation. All three presented with a GCS score of 15.[50] However, cases without adverse sequelae following blade removal have been described.[30, 43, 51]

Bullock and van Dellen describe an unusual case of an acute carotico-cavernous fistula with a retained transorbital knife blade.[52]

One problem in identifying retained foreign objects is that retained non-opaque foreign objects may not be visible on X-rays.[46] Computed Tomography, Magnetic Resonance Image or ultrasound scans may be needed for identification.

Intracranial injuries and complications

Early intracerebral injuries and complications include:

- Direct injury to the brain or cranial nerves
- Vascular injuries involving both the arterial and venous structures, with risks of subarachnoid, subdural or extradural haemorrhage
- Pneumocephalus
- CSF fistulae
- Infections such as meningitis, ventriculitis, tetanus and abscess formation
- Seizures

Late intracerebral injuries and complications include:

- Late vascular injuries, such as CCF's and false aneurysms
- Seizures
- Persistent neurological deficits
- Infective complications [2(pp80-90), 11, 42]

Brain parenchymal and cranial nerve injury

Direct injury to the brain is dependent on the site of the injury. This can vary from hemiplegia to change in personality.[2(pp80-81)]

Perorbital stabs are likely to cause damage to the 2nd, 3rd, 4th and 6th cranial nerves. As described above, a knife is more likely to be directed to the orbital apex where the optic nerve passes through the optic canal and the 3rd, 4th and 6th cranial nerves traverse the cavernous sinus and superior orbital fissure.[36]

Birch-Hirchfeld reviewed 172 cases, of whom 125 had optic nerve injury.[39] In the series of de Villiers and Sevel, 6 patients had injury to the globe, of whom 4 lost sight in the injured eye.[15, 16] In van Duinen's series, optic nerve injuries occurred in 34% of surviving patients; in 11% without damage to the other orbital cranial nerves.[2(pp84-85)]

Contralateral injury i.e. injury to the neurovascular structures opposite to the stab site has been described.[22-24, 49]

Paranasal sinus involvement and pneumocephalus

Penetration through the paranasal sinuses can lead to pneumocephalus.[53] Conversely, pneumocephalus indicates a paranasal sinus injury and high risk for infection.[2(p83)] Injuries that breach a mucosal surface have a higher incidence of infection.[50] In the series by van Duinen, 17 patients of 347 developed pneumocephalus.[2(p83)]

Cerebrospinal fluid fistulae

Transient CSF leaks at the time of injury occur commonly. The development of a new CSF leak often (80%) settles spontaneously. Persistent CSF leaks however, need to be treated, as 25% of them are associated with meningitis.[2(p83)]

Infective complications

Any breach of the coverings of the brain poses a risk for infection.[54, 55] Transorbital stab wounds and those with retained blades have also been identified as high risk groups for both vascular and infective complications.[50] If meningitis is suspected, a lumbar puncture should be performed prior to commencement of antibiotics. In de Villiers' series, meningitis developed in 3 patients. All presented between 2 days to 2 weeks after the injury.[16] In the series by van Duinen, 22% had infective complications (usually abscess); the commonest organism was *Staphylococcus aureus*.[2(p78)]

Prolonged sepsis may occur when an object is retained for a long period of time. Tetanus is commoner with penetrating injuries occurring in an agricultural environment, as these often involve wood fragments contaminated with *Clostridium tetani*.[15, 16] Orbital gas gangrene has also been described.[40]

De Villiers and Sevel recommended prophylactic antibiotics.[15] Taylor and Peter state that they do not routinely use prophylactic antibiotics in cases of penetrating wounds to the head, and have not had a higher incidence of infection over a 10 year period.[50] These opposing viewpoints have been argued by many other authors.[2(pp78-79)]

Seizures

As with any brain injury, the patient is at risk for seizures acutely or chronically. Although anecdotally uncommon with penetrating head injuries, there are little reported data on this risk.[16]

Intracranial vascular injuries and complications

Vascular complications include:

- Direct or indirect vessel injury with acute bleeding
- False aneurysm formation
- Carotid artery injury leading to transection, occlusion, false aneurysm or CCF.[2(pp87-90)]

Some authors state that vascular complications such as traumatic aneurysms and carotico-cavernous fistulae are not common. The presentation may however occur days to weeks following orbital penetration and not be recorded.[42] In some series, up to a third of penetrating stab wounds to the head had vascular complications.[18, 56] Vascular injury is also more common with perorbital rather than vault stabs. Perorbital stabs are likely to cause damage to cranial nerves II to VI, and the internal carotid artery (which is tethered in the cavernous sinus).[36] In the series by de Villiers and Sevel, 5 patients (50%) had carotid artery injuries (1 internal carotid artery occlusion, 2 carotid-cavernous fistulae and 2 internal carotid artery false aneurysms). One false aneurysm was supraclinoid and one infraclinoid.[15, 16] This 50% risk was supported by the series on head stabs reported by Kieck and de Villiers. Of 20 that were stabbed in the orbit, 18 had an angiogram. Of these, 11 had a vascular injury – 4 carotico-cavernous fistulae, 3 false aneurysms, 1 occlusion, 1 transection and 2 delayed vasospasm. This is in contrast to the 56 patients who had cranial stabs and angiography, with only 15 vascular lesions.[18] In the series by van Duinen, 31 cases (9%) had a vascular injury – 14 CCF's, 12 traumatic aneurysms and 5 carotid artery occlusions.[2(p87)]

Acute extraxial haemorrhagic collections

Although acute subdural, extradural or subarachnoid haemorrhage would seem likely following transorbital stabs, there are only 2 case reports describing this type of vascular complication. In a patient with a switchblade knife injury to the left orbit, the knife passed through the lateral orbital wall, the globe and the ethmoid sinus and lodged with the tip in the right anterior frontal lobe, resulting in an acute right subdural haematoma. There were no neurological sequelae.[57] In a patient with a single transorbital retained knife blade that had penetrated a depth of 5cm, a delayed subdural haematoma and brain abscess were reported. The blade was removed at surgery.[50]

False (traumatic) aneurysm

Most cerebral artery false aneurysms occur as the result of missile injuries or motor vehicle accidents. Most following blunt trauma are peripheral in location. Traumatic aneurysms have been reported as uncommon following non-missile penetrating injuries.[58-60] Traumatic aneurysms of the carotid artery [15, 16, 18, 41, 61] and of the anterior choroidal artery [62] following transorbital stabs are well described.

In the series by Kieck and de Villiers, a total of 11 false aneurysms were identified. Of the 8 due a transcranial stab, 3 were peripherally located and 5 were at the base of the brain. Of the 3 false aneurysms due to a transorbital stab, all were located at the base of the brain. These had an almost double the rate of rupture when compared to those false aneurysms located peripherally (71% vs. 43%). Most (88%) were detected within 3 weeks of the injury.[18]

Although Du Trevou and Van Dellen reported 21 traumatic aneurysms and 49 penetrating orbital stab wounds in their large series of 330 patients who had sustained penetrating stab wounds to the head, there is no information in the article to allow further analysis of these data. They state that traumatic aneurysms may be identified within hours of the injury, and can rupture at any time after formation. When rupture occurs, the mortality is high.[1]

The decrease in the use of angiography and the increased use of CT in the evaluation of penetrating head trauma may have resulted in an artificially reduced incidence of traumatic aneurysms. The CT scan will demonstrate the intracranial haematoma, but can miss the associated aneurysm.[59, 63] Aneurysms may therefore have a delayed presentation with intracranial haemorrhage.[64] For penetrating head trauma, this delayed presentation has a significantly higher mortality (41%) than when the aneurysms are detected at incidental angiography (16%).[65]

Carotico-cavernous fistula

The carotid artery is tethered within the cavernous sinus and is therefore prone to direct injury from a knife traversing this region via the medial SOF. This can result in a carotico-cavernous fistula. Of the 14 CCF cases in the van Duinen review, 4 died.[2(pp89)] Other cases have also been described.[22, 66]

Orbital injuries and complications

The orbital complications include:

- Damage to the globe
- Optic nerve damage
- Injury to the 3rd, 4th, 5th (1st division) and 6th cranial nerves.[2(pp84-87), 36]

Imaging

Imaging modalities and practises change rapidly. Although the initial investigation of orbital stabs could be a skull X-ray to exclude a retained object, the current definitive investigation should be a CT head to also exclude intracranial penetration.[21] Prior to the advent of CT, clinical evaluation, skull radiography and angiography were used.

Skull radiography

Standard skull radiography could nonetheless be performed to identify retained objects and slot fractures. Further dedicated radiological views of the orbital structures could also be performed to identify fractures in the orbital roof, optic canal and orbital fissure.[15] Even detailed radiography may not demonstrate orbital fractures in 20 to 50% of cases.[36, 40] The other problem is that a retained foreign object may be translucent on radiography.[46] In most cases this should be visible on CT.

Computed Tomography (CT)

The management of penetrating head trauma before the advent of CT scanning was predominantly surgical, without or with arteriography.[15] Nowadays a CT scan of the head will almost invariably be performed in the acute setting. An initial CT scan can be used to assess the position of the blade or foreign body and any possible associated haematoma or intracranial air or sinus blood. Subarachnoid blood in the basal cisterns may assist in the interpretation of subsequent angiography.[52] Modern CT scanners limit metal artefact and the angle of the slices can be altered to further reduce metal artefact arsing from retained objects.[50, 52]

Retained foreign bodies such as wood fragments can be identified on CT.[12] However, dry wood may have an attenuation similar to air and fat, and be difficult to identify.[67, 68] Foreign bodies may sometimes only be demonstrated once further complications such as abscesses have developed.[11] Metallic foreign bodies are identified by their high attenuation and associated beam-hardening artefact.[21] Removal of a retained foreign body under CT guidance has also been described.[13, 69]

In cases with anterior base of skull CSF leakage, fine-slice coronal CT's of the anterior cranial fossa may delineate the exact site of injury prior to repair. Some authors suggest repeat CT scans at 1 month post-injury to exclude the development of insidious abscesses.[52]

Although many findings can be demonstrated on direct ophthalmological examination, CT is also able to identify injuries such as hyphaema (haemorrhage into aqueous humour), intravitreous haemorrhage, lens subluxation/dislocation, choroidal detachment, retinal detachment, globe disruption, orbital haemorrhage and optic nerve injury.[21]

Magnetic resonance imaging (MRI)

MRI would not be the appropriate investigation at the initial presentation. An important reason for this is that the penetrating object may be metallic and could cause (further) injury to the globe within the involved orbit when subjected to the magnetic forces within the MRI room.[21]

Indications for MRI include identification of foreign bodies not seen on CT and assessment of complications such as abscesses.[11, 12] MRI is less sensitive than CT for the detection of wooden foreign bodies, but can be utilised if the CT examination is negative. T1-weighted images provide the best contrast between wood and surrounding orbital fat.[21] In cases where the penetrating object has already been removed at the time of presentation, an MRI may be more sensitive than CT to the presence of small amounts of blood products. In standard practice, fast spin-echo T2-weighted sequences are generally used in preference to spin-echo T2-weighted sequences due to their considerable time-saving, despite their lesser sensitivity to blood products. A T2*-weighted gradient echo sequence is more sensitive and may be required to demonstrate blood products.[14] There are no published reports on the use of Gadolinium-containing contrast agents in the identification of retained orbital foreign bodies.

Angiography

Angiography is required if the plain radiographs demonstrate that the knife may have traversed a vascular territory.[15, 43] This is especially so for all patients presenting with transorbital stabs, as there is then a high incidence of injuries to the internal carotid artery and proximal portions of the middle or anterior cerebral arteries.[70] Another high risk group are those with a retained sharp object.[16, 43, 52] Removal of knives can be performed with the angiographic catheter still in situ in order to allow immediate angiography after removal of the knife.[52] Although post-removal angiography is not always performed,[43] repeat angiography at 2 weeks can be performed to exclude late development of false aneurysms.[52]

Using CT for initial assessment, indications for angiography now also include CT features added to the clinical presentation and slot fractures on skull x-ray. Features suggesting traumatic aneurysms include delayed neurological deterioration, presence of a large intracerebral haematoma following trivial trauma, unexplained major arterial bleeding during the surgical evacuation, unusual amounts or distributions of subarachnoid haemorrhage on initial CT and displaced skull fractures (especially if the location is basal).[70]

With stabs to the head, Melvill et al have suggested that angiography should be performed at 7-10 days for maximal yield. If this demonstrates spasm, it should be repeated 7-10 days later.[18, 71, 72] Unlike previous studies, none of their patients developed secondary haemorrhage from ruptured traumatic aneurysms. Vasospasm on initial angiography was associated with high mortality, but no traumatic aneurysms were identified on repeat angiograms in survivors in this group. They suggest that although delayed development of aneurysms has been recorded following blunt injury, they appear to develop more rapidly following penetrating injury. They suggest that an angiogram should be performed soon after admission or after initial emergency surgery. Patients with vasospasm or a cut-off vessel on initial angiography should have a repeat study.[1]

Lumbar puncture

It is worth noting the review comment by Schmidek that a lumbar puncture is still the most sensitive method of confirming subarachnoid blood and hence a breach of the dura mater.[25] This investigation can also confirm meningitis.[16]

Management

All cases who have had a stab to the head could have a skull radiograph performed. This may identify an indication for a CT scan such as a slot fracture, retained blade or pneumocephalus. All those patients that present with depressed levels of consciousness or neurological signs already have an indication for a CT head scan and may not undergo a skull radiograph in many centres.

Clinical assessment, skull radiographs and CT scans should determine whether immediate angiography is necessary.[50] Even if there is no neurological injury or intracranial vascular injury on CT, angiography is required if the plain radiographs or CT demonstrate that the knife may have traversed a vascular structure.[43]

In the cases of a retained blade, there are several methods of removal. If there is a vascular injury, endovascular or surgical management should be considered prior to knife removal. If there is no injury, the knife can safely be removed under general anaesthetic in a controlled operating theatre environment. The knife can be removed by attaching a Vise-Grip pliers and knocking it out along the path of insertion with a mallet.[50] When removing an object with a serrated edge, pressure towards the non-serrated edge without alteration of the angle of pull is helpful.[73] Knives can also be removed with an associated craniectomy around the impacted blade. Although post-removal angiography is not always performed, removal of the knife can be performed with the angiographic catheter still in situ to allow immediate angiography after removal of the knife.[43, 52] An alternative is an immediate CT scan to assess for haemorrhage.[50] If a retained knife is identified incidentally and there are no features of sepsis, it is left in situ. If there are features of sepsis, it is removed.[43]

Schmidek holds that in a unit with a high volume of cases, a selective approach is reasonable, but the doctor who only encounters an occasional case should adopt a more aggressive approach.[25]

The full range of neurosurgical approaches to the management of this problem is beyond the scope of this dissertation.[2(pp71-77)]

Outcome

In the series of 10 cases reported by de Villiers and Sevel, of the 7 survivors, only 3 recovered fully; 2 had a visual deficit, 1 had a hemiparesis with visual deficit and 1 remained an "akinetic mute".[15, 16]

Five cases of transorbital penetrating injury with a normal outcome have been described. Jackson et al describe a switchblade knife injury to the left orbit where there were no neurological sequelae.[57] Van Dellen and Lipschitz describe a single case who was stabbed through the right lateral orbital wall with the tip at the base of skull. Pre and post removal carotid angiography were normal. There were no sequelae.[43] Hickman described a single case of a retained knife in the upper outer orbit. The knife traversed the lateral orbit, orbital floor, posterior wall of the maxillary sinus, pterygopalatine fossa with the tip anterior to the 4th cervical vertebra. Angiography was normal and there were no sequelae.[74] Nath et al describe a single case of a stab with a bread knife that entered at the right infraorbital margin, traversed the ethmoid sinus and crossed the midline at the level of the tuberculum sellae. There were no neurological or endocrine sequelae.[73] Lichter et al report a case of a retained knife blade in the right orbit which was removed without sequelae. They performed preoperative CT and angiography and used antibiotic prophylaxis.[31]

Van Duinen summarised the outcome of 129 cases for the period from 1977 to 1997. Of the 87% of survivors, neurological recovery occurred in 83%, 28% of whom were left with visual and/or cranial nerve disturbances. Severe injuries occurred in 12%, moderate injuries in 2% and 3% had an unknown outcome.[2(p114)]

Even in cases of penetrating eye injury without transorbital intracranial penetration, a delay in presentation and alcohol use was associated with a poorer prognosis.[26]

AIM

The aim of this study is to perform a retrospective review of all cases of low-velocity non-missile penetrating orbital trauma with intracranial complications presenting at Groote Schuur Hospital over the 5 year period between 1997 and 2001.

METHOD

Ethical approval was obtained from the Faculty of Health Sciences Research Ethics Committee at the University of Cape Town. Standard confidentiality regarding patient records was maintained throughout the study. This study was compliant with the World Medical Association Declaration of Helsinki on ethical principles for medical research involving human subjects.[75]

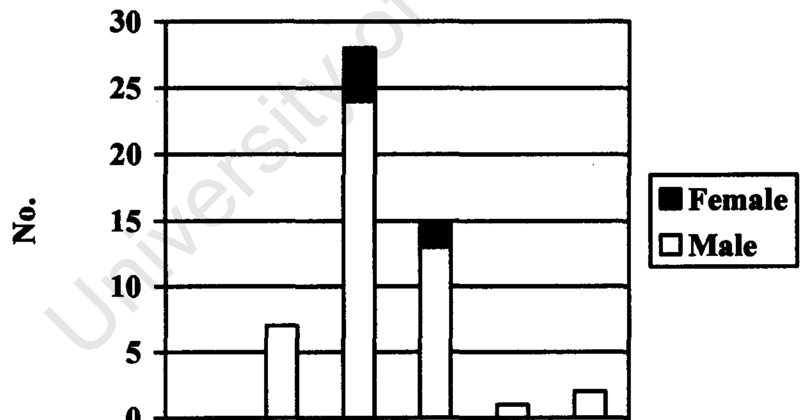
The names of all patients who were recorded as having experienced penetrating orbital injury were retrieved from the discharge summaries in the Departments of Neurosurgery and Ophthalmology, Groote Schuur Hospital, in the 5 years between 1997 and 2001 (inclusive). The patients folders, microfilms and radiology records were further reviewed to identify those patients who had a transorbital penetrating injury with evidence of intracranial complications. Some patients, such as one with a retained knife and another with carotid-cavernous fistula have been described before in the literature, and were included.[50, 66] All the data collected are presented in the Appendix.

RESULTS

Demographics

A total of 1245 orbital injuries were identified in the 5 year study period. In this group, 3 had injuries to both eyes; 1 case presented with a repeat injury to the same eye on a separate occasion and 5 cases presented with an injury to the opposite eye on a separate occasion. Of these, 284 cases were excluded due to their assaults being by unidentified blunt objects, stones, bricks, feet, gunbutts, gunshots or wound rupture following previous surgery. Therefore of 961 cases with potential intracranial complications, a total of 53 patients with non-missile transorbital intracranial penetrating injuries were extracted. There were 47 males and 6 females, with an age range from 17 to 57 years and a mean age of 28 years (Table 1).

Table 1: Age and gender distribution



	0-10	11-20	21-30	31-40	41-50	51-60
Female	0	0	4	2	0	0
Male	0	7	24	13	1	2

Instrument

The mechanism of injury was usually a stab with a knife (Table 2).

Table 2: Type of instrument used

Instrument	Knife	Screwdriver	Other
Number	48[#]	4[*]	1[§]

[#] Nine of this group had a knife retained in the orbit at presentation. The remainder were deduced to be knife wounds from the history or examination findings

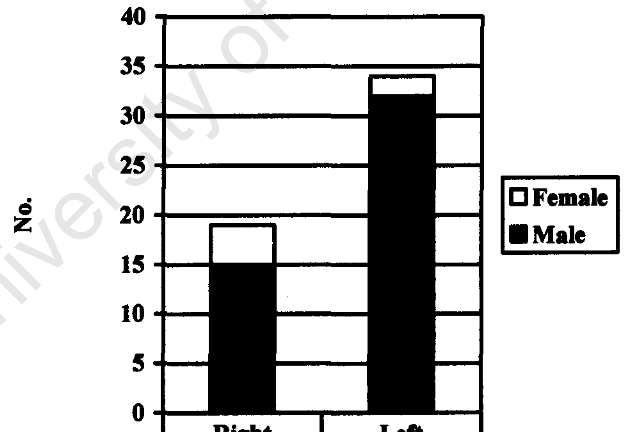
[*] One had a screwdriver retained in the orbit at presentation. The remainder were from patient description

[§] Gemsbok (a type of antelope) horn

Side and site of injury

The right eye was injured in 19 cases and the left eye in 34 cases. Differences in side of injury by gender are shown in Table 3. Information on the exact site of the orbital penetration was incomplete. The available data is shown in Tables 4, 5 and 6. From this data, injuries occurred more frequently in the superior and medial parts of the orbit.

Table 3: Side of injury according to gender



	Right	Left
Female	4	2
Male	15	32

Table 4: Specific quadrant of injury within orbit

	Right orbit*	Left orbit*	Total*
Medial/superior	1 (case 18)	4 (cases 13#, 21, 22 and 24)	5
Medial/inferior	0	2 (cases 13# and 43)	2
Lateral/superior	2 (cases 6 and 19)	1 (case 2)	3
Lateral/inferior	0	1 (case 48)	1

* Exact site of injury not defined in 16 cases on the right and 27 on the left

Case 13 involved both medial quadrants

Table 5: Site of injury within orbit relative to the horizontal plane

	Right orbit#	Left orbit#	Total#
Medial	4	7	11
Lateral	2	7	9

Exact site of injury not defined in 13 cases on the right and 20 cases on the left.

Table 6: Site of injury within orbit relative to the vertical plane

	Right orbit#	Left orbit#	Total#
Superior	9	13	22
Inferior	1	2	3

Exact site of injury not defined in 9 cases on the right and 19 on the left

Retention of instrument at presentation.

Of the instruments still *in situ* at presentation, 9 were knives and 1 was a screwdriver (Table 7).

Table 7: Retained instruments

	Right	Left	Total
Retained	2[#]	8[*]	10
Not retained	17	26	43

[#] One in medial orbit

[*] One medial, 1 lateral, 3 superior and 1 inferiorly situated in orbit

Delay prior to admission

Those cases that presented late are shown in Table 8. Most of these cases presented with CCF's. The CCF's that did not fall into this group (cases 26, 28, 30, 50) had insufficient data for assessment and may well have presented late. Meningitis accounted for the 2nd largest group of those with delayed presentation to hospital. Those cases of meningitis that did not present late, all had a depressed level of consciousness (cases 9, 12, 14 and 20). Case 20 also had intracranial haemorrhage at the time of the initial injury requiring urgent admission. In 2 cases with meningitis (cases 37 and 45), it was not possible to ascertain time from injury to admission.

Table 8: Delay prior to admission to hospital

Delay before admission	Pathology	Case Number
1 day	Pneumocephalus, seizures	2
1 day	Meningitis	6
1 day	Pneumocephalus, IVH, SAH, meningitis	8
1 day	CCF	15
1 day	Meningitis, ICH	43
2 days#	Meningitis	3
5 days	CCF	10
1 week	CCF	29, 47
8 days	ICH	42
2 weeks	CCF	52
27 days*	Meningitis	44
45 days	CCF	1
3 months*	CCF	40
4 months	CCF	23
3 years	CCF	25
4 years	CCF	34

Also admitted again at 86 and 163 days

* Seen originally at time of injury and discharged from hospital

Injury to globe

Globe injury, presence of an afferent papillary defect and/or ocular motility at admission are recorded in Table 9. In the 24 eyes that were blind at discharge or follow-up, the cause of blindness in 9 was significant direct globe injury and in 6 it was due to CCF (3 together with globe injury, 2 without globe injury and 1 with insufficient data). Five were due to presumed optic nerve injury on the basis of clinical notes (cases 7, 16, 27, 32 and 44 - none of whom had globe injury) and 4 from unknown causes (cases 6, 18, 21 and 42).

Table 9: Globe injuries

		Globe injury present (n=16)	No globe injury (n=33)	Insufficient data (n=4)
Visual acuity	**Normal**	-	7	-
	Measurable VA (≥6/60)	1	6	-
	CF	-	5	-
	HM	-	1	-
	PL	2	1	-
	NPL	13	10	1
	Not recorded	-	3	3
Afferent papillary defect	**No defect**	1	10	-
	RAPD	3	12	-
	TAPD	7	4	-
	Not recorded	5	7	4
Ocular motility	**Normal**	2	8	-
	Decreased	1	9	-
	None	6	8	-
	Not recorded	7	8	4

Neurological deficits at presentation

Glasgow Coma Scale and presenting clinical features are listed in Table 10.

Table 10: GCS relative to the clinical features at presentation.

GCS	Normal	CCF	Focal Neurology	Isolated depressed GCS	Meningitis	Not recorded
<13	0	1#	5#	3	3	0
13-14	3	0	2	0	0	0
15	2	11	5	0	12	2
Not recorded	0	2	1	0	0	2

One case with a CCF also presented with focal neurology

Injuries and complications

There were 2 deaths (cases 8 and 36), both due to massive intracerebral haemorrhage. No complications were present in six cases. Of these, 3 had a retained knife (cases 24, 48 and 49) and 3 had pneumocephalus (cases 19, 38 and 51). Seven people had no long-term sequelae. Fifteen cases had single complications. The remainder had several complications. These are correlated in Table 11.

Table 11: Combinations of complication categories

	Vascular	Visual	Neurological	Seizures	Infective	Death
Vascular	**6**	17	7	3	5	2
Visual		**6**	5	3	8	0
Neurological			**0**	4	2	0
Seizures				**0**	1	0
Infective					**2**	1
Death						**0**

Note: The values in bold are cases that only developed one type of complication each. All other cells indicate combinations of complications.

Of the 19 cases with pneumocephalus, only 6 developed meningitis. However, there were a further 7 cases of meningitis that were not associated with pneumocephalus. In this group without pneumocephalus, 1 did not involve a paranasal sinus (case 41), 2 involved a paranasal sinus (cases 20 and 44) and in 4 the data were insufficient. The relative risk ratio of meningitis following pneumocephalus was 32% (6/19) versus 21% (7/34) without pneumocephalus.

The vascular complications are shown in Table 12. The 2 commonest findings were intracerebral haematoma in the knife track and CCF. Intracerebral haemorrhage or visible knife tracks involved mainly the frontal (8) and temporal (9) lobes together or alone. There was also involvement of the parietal lobe (1), the basal ganglia (3) and the cerebellar regions (1). No data were obtainable in 3 cases.

Eight CCF's were present on the right and 6 on the left. Vascular injuries associated with the CCF's included infarction (case 50), ICH (case 34), IVH (case 34) and SAH (cases 34 and 50). All were treated with balloon embolisation, except for cases 29 and 50 who were discharged pending the arrival of the required embolisation equipment. No further follow up was available.

All but one (case 5) of the 13 cases of SAH had associated intracranial vascular injury with ICH identified in 8 cases.

Of the 6 cases with SDH, 4 were associated with ICH. The other two cases of SDH (cases 6 and 44) were isolated findings.

Intraventricular haemorrhage occurred in 5 cases, and in all but one case this was an extension from an adjacent ICH. The 2 deaths (cases 8 and 36) both had IVH.

The 3 cases with infarction were associated with ICH (case 17), SAH (case 27) and CCF (case 50).

Two false aneurysms were identified (cases 4 and 16). Both these cases also had an ICH and one each had an IVH and SDH.

Table 12: Vascular complications

Vascular injury	Number*
ICH	19
CCF	14
SAH	13
SDH	6
IVH	5
Cerebral infarction	3
False aneurysm	2

*Note that more than 1 pathology was identified in 15 cases

There were 11 cases with persistent neurological deficits at time of discharge. These data are summarized in Table 13. All but one (case 3 with meningitis and aphasia) were associated with a vascular injury. Cases 13 (mild hemiplegia and aphasia), 21 (aphasia) and 51 (monoplegia) were evident at presentation, but resolved prior to discharge and were not included in this data subset.

Table 13: Persistent neurological deficits present at time of discharge.

Neurological deficit	Number*
Hemiplegia	7
Speech difficulties	3
Mental impairment	1
Insufficient data	1

*Note that more than 1 pathology was identified in case 13.

Antibiotic use

Twenty-seven cases were given antibiotics. Thirteen of these had meningitis based on clinical and/or CSF findings. The other 14 received prophylactic antibiotics. No antibiotics were given in 18 cases. Three cases presented with very late onset CCF's and did not receive prophylactic antibiotics. Clinical information was inadequate in 5 cases.

Anticonvulsant use

Thirteen cases were given prophylactic phenytoin to prevent seizures. Five cases not given prophylactic anticonvulsants developed seizures and subsequently required phenytoin. These were case 2 (with pneumocephalus), case 16 (with meningitis, ICH, IVH and FA), case 18 (with ICH), case 35 (with retained knife) and case 46 (with SDH, ICH and pneumocephalus). Twenty-nine cases did not receive anticonvulsants. Insufficient data were recorded in 6 cases.

Follow up after discharge

One case died at admission (case 36) and another at 6 days (case 8). Of the 30 who did not return for follow-up, 11 were blind or had poor visual acuity at discharge, 11 were well despite complications following the injury, 4 had neurological deficits (1 case was also blind) and 4 had insufficient data for assessment. Of the 21 who returned for follow up, 16 returned within 9 months (mean of 3½ months) and 5 at 16, 27, 36, 42 and 60 months respectively.

Skull radiograph findings

Table 14 lists the imaging findings on the skull radiographs. Of the 20 skull radiographs not available for review, 3 were considered to be normal and 2 would have shown retained knives.

Table 14: Skull radiograph findings

Finding	**Number***
Normal, unrelated or old pathology	15 (18)#
Retained object	8 (10)#
Pneumocephalus	5
Fracture	5
Sinus opacification	3
Radiograph not available for assessment	20 (15)#

*Note that more than 1 pathology was found on some radiographs

#When reviewed with CT findings.

The sensitivity of the skull radiograph for detecting findings is shown in Table 15. Where both a skull radiograph and CT were performed, the sensitivity for detection of a significant abnormal finding on skull radiograph was 40%. As certain findings such as intracranial haemorrhage would not be expected to be seen on skull radiographs, the adjusted sensitivity for skull radiographs was 66%. Retained objects are usually easily visible on a skull radiograph. If the contribution from retained objects is omitted however, the sensitivity for detection of a significant abnormal finding on skull radiograph falls to only 34%.

Table 15: Sensitivity of skull radiograph findings compared to CT

Finding	Skull radiograph (no.)‡	CT (no.)‡	Sensitivity of skull radiograph (%)
Normal	14*	1*	7*
Pneumocephalus	5	9	56
Fracture	5	12	42
Sinus opacification	1#	5	20
Retained object	7$	7	100
Overall			40*

‡ Only 31 patients had both skull radiography and CT head performed. 1 case had combined sinus opacification and pneumocephalus.

* In 1 case of meningitis (case 41), the skull radiograph and CT were both normal. The skull radiographs were expected to be normal in 13 cases as they would not have demonstrated pathology such as intracranial haemorrhage which would only be shown on CT. The only true missed finding was opacification of the sphenoid sinus (case 10).

\# Unable to compare 2 cases as the CT study did not include the area of interest.

$ In 5 of the 7 cases where both a skull radiograph and CT were performed, the knife was removed prior to CT, but would be expected to have been seen. Only 1 case of the 8 with a retained knife seen on skull radiograph did not have a CT performed.

CT findings

Table 16 lists the findings found on CT head and orbit scans. Of the 4 cases with completely normal findings, 3 had CCF's and 1 had meningitis.

Table 16: CT head findings

Finding	Number*
Fracture	23
Pneumocephalus	19
Intra-axial collection (ICH), knife track and infarct	16
Extra-axial collection (SAH, SDH, EDH)	15
Sinus opacification	9
Retained instrument	6
CCF	5#
Normal	4
Abscess	1
Data incomplete	4

*Note that more than 1 pathology was found on some CT imaging studies

#Five of the CCF's were diagnosed on CT and one on MRI.

Table 17 compares the ability of CT to detect any vascular injury with that of angiography. Overall, CT has a sensitivity of 82% (95% CI 66-98%), but a specificity of 53% (95% CI 28-79%) for the presence of vascular injury. Of the 10 cases of CCF, only 6 were detected by CT. The delays between CT and angiography in these 4 CT-false negative CCF cases were 3 days, 3 months and unknown in 2 cases. Of the 3 cases of false negative CCF, 1 had clinical features of CCF and 2 had incomplete data. In the remaining 9 cases that had a normal CT (for vascular injury), 1 demonstrated spasm of the ipsilateral ophthalmic artery and 8 were normal.

Table 17: Sensitivity and specificity of CT findings compared to angiography for the assessment of vascular injuries.

	Angiography Normal	**Angiography Abnormal**	**Total**
CT normal (no vascular injury)	8	4	12
CT abnormal (vascular injury present)	7	18	25
Total	15	22	37

Note: Only 35 patients had both a CT head and an angiogram performed. Cases 14 and 16 had 2 angiograms each.

Angiography findings

Table 18 lists the angiography findings. One patient (case 16) with normal findings on angiography performed at 6 days had a false aneurysm demonstrated on follow-up angiography performed at 26 days.

Table 18: Angiography findings

Finding	**Number**
Normal	14
CCF	14[#]
Spasm	5
Vascular structures deviated by collection/brain swelling	3
False aneurysm	2
Retained knife in close contact with vessel	2
Incidental	1[*]
Not performed	13

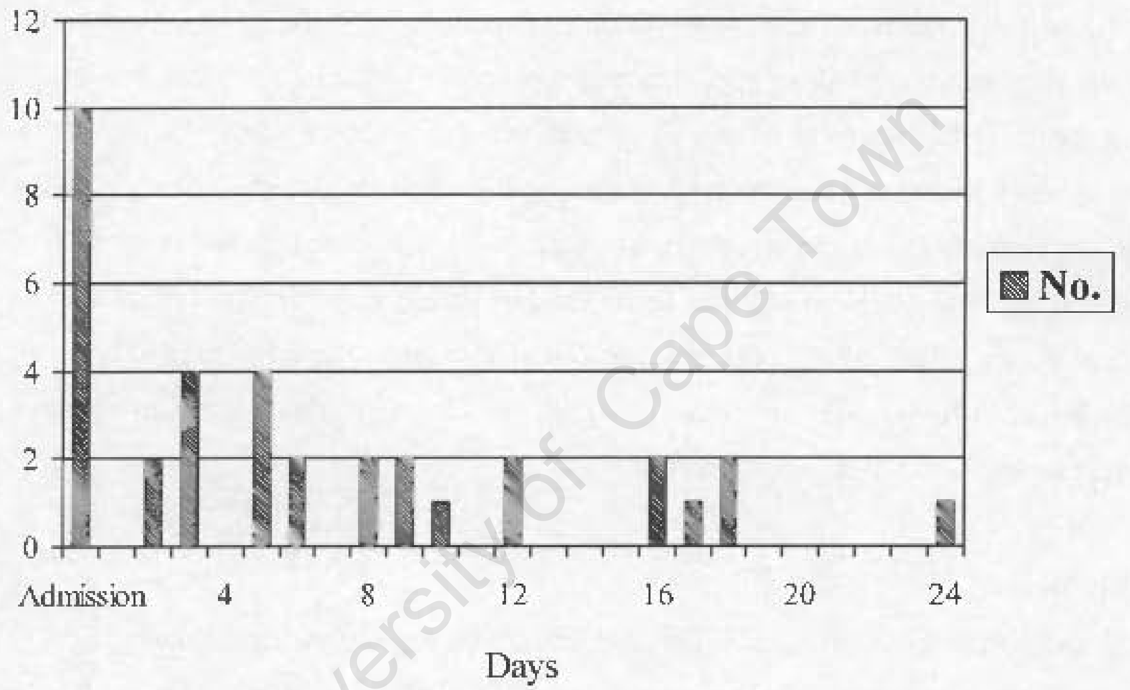
[#] Eight on right, 6 on left

[*] Posterior communicating artery aneurysm

Delay to angiography

Graph 1 lists the delays from time of admission to angiography. Of the 10 cases that had angiography at admission, 8 were for retained objects, 1 had a large ICH (case 13) and 1 had a large ICH and SDH (case 46). Of the 2 retained objects that were removed without prior angiography, one did not have an angiogram and one had angiography performed 12 days after admission. An angiogram was not performed in 13 cases and no time interval data were available in 6 cases.

Graph 1: Delay from admission to angiography



DISCUSSION

Study limitations and problems encountered

All the data obtained were retrospective and, therefore, limited by various difficulties in retrospective studies of this nature, including incomplete patient collection, inadequate data and changes in the standard protocols of investigation and management. Any patients seen but not admitted or who died prior to further intervention received a brief "discharge" summary. Those who were found not to have an intracranial injury on CT were referred to Ophthalmology for management of the ocular injury. Management protocols for the trauma unit however dictated that any penetrating orbital injury could have been referred to one or both of Neurosurgery or Ophthalmology. Injuries assessed at primary care facilities and secondary hospitals would be assumed to have been referred to a tertiary centre. Children admitted to the separate tertiary care paediatric hospital in Cape Town, patients dying prior to admission to hospital or after admission to hospital but prior to neurosurgical or ophthalmological assessment are almost certainly under-represented due to data collection problems.

Incidence

Although only 53/961 (6%) of patients admitted with penetrating orbital injury had intracranial injuries identified, this figure should be viewed in a broader context. These data exclude children, patients that died prior to admission, those seen at the other tertiary referral centre within Cape Town and injuries due to firearms, machetes or blunt assaults. As 1245 cases of orbital injury could be collected over a 5 year period at a single South African institution, this represents a staggering load of trauma in the community. Due to lack of a central trauma registry and other factors, it is not possible to extrapolate the full extent of this impact on the country as a whole.

Demographics

In this series, 89% of cases occurred in males, with the median age being 28 years. This finding is not unexpected as trauma in general affects young males.[1, 15, 16, 18] In contrast, almost half of all cases described in the literature have occurred between the age of 1 and 13 years.[2(pp23-25)]

Mechanism of injury

This series of 53 cases is the largest single series of non-missile transorbital intracranial penetrating injuries due to assault that could be found. Unlike other reports, where only 24% (84/347) of injuries were due to assault, none of the injuries in this study was due to a fall in an elderly person or suicide.[2(p26)] Almost half of all cases described in the literature have been accidental injuries occurring between the age of 1 and 13 years.[2(pp23-25)]

Instrument

The intentional traumatic nature of the injury explains the use of aggressive instruments such as knives and screwdrivers, which were used in all but one of the cases. In this last injury, a gemsbok horn was presumably the nearest available weapon to hand.

Site and side of injury

A total of 14 cases had lid injuries and 12 had skin wounds visible around the eye. Unfortunately, over half (27) of the cases had insufficient data concerning the exact site of injury. The absence of information precluded further assessment as to whether the wound was visible at presentation.

Although not as marked as in the literature, where 43 to 70.5% of assaults involved the left eye, 64% of injuries in this study involved the left eye. Most assailants are presumed to be right handed.[1, 2(p25)] There are no published data to suggest that the handedness in South Africa is different to the rest of the world.

In the horizontal plane, even though there appears to be a predominant involvement of the medial (11/20) rather than lateral orbit, the lack of detailed data in 33 of 53 cases precludes further meaningful assessment. Likewise, the predominant involvement of the superior orbit (22/25), rather than the inferior orbit may be spurious. Insufficient data

(28/53) also prevents further analysis as to whether the site of injury relates to the type of intracranial injury sustained.

Retention of instrument at presentation

A total of 19% (10/53) of the instruments were retained in the skull at the time of presentation. This is similar to the 25% reported in the literature.[2(p49)] In this study, 3 of the 10 cases with a retained knife at presentation suffered no complications. This compares to 4 out of 43 cases without a retained knife at presentation who suffered no further complications. Both cases that died did not have a retained knife at presentation. This observation is supported by the literature, where those in whom the knife was removed by the assailant did worse than those with a retained knife at presentation. This difference has been proposed to be the result of side-to-side movement causing injury during extraction of the blade.[43]

Delay prior to admission

Most of the cases that presented to hospital more than a day after the assault in this study had a carotico-cavernous fistula (9/14). Carotico-cavernous fistulae presented between 1 day and 4 years later. In four cases of carotico-cavernous fistula, insufficient data were available to determine the delay. After CCF's, the next most common cause of delayed presentation was meningitis (5/16), occurring between 1 to 27 days. This finding is similar to previous local publications.[16, 36]

Skull radiograph findings

The skull radiograph alone had poor sensitivity for detecting intracranial injury. Even by excluding findings that would not be expected to be found on skull radiograph, the best sensitivity was 79% in those cases that had both skull radiographs and CT's performed.

CT Imaging

CT is an accurate means of identifying life-threatening complications such as SDH and EDH that require immediate management. The exact site of injury and the presence of intracranial penetration can be confidently detected on CT. The presence of pneumocephalus is a predictor of further complications such as meningitis.

The overall sensitivity of CT for detecting vascular injury when compared to angiography as the gold standard is 82% (range 66-98%), which is reasonable. However, the specificity is only 53%. Three cases with normal CT head scans (i.e. without vascular injury) were found to have CCF's on angiography. Due to the incomplete data, it is difficult to assess the reason for this. The CCF may have developed during the delay between the CT and angiogram. It is also not known whether these cases would have been detected clinically.

A large group of patients with intra-axial and/or extra-axial haemorrhage seen on CT had normal angiography. Only 1 of 16 had a repeat angiography (18 days later) and this demonstrated a small false aneurysm that required neurosurgical clipping (case 16).

CT scan of the head without intravenous iodinated contrast medium is useful, but the high false negative rate of 18% for potentially serious injury is concerning. From the data presented in this thesis, some form of angiography should be mandatory in the majority of patients.

Angiography

Conventional catheter angiography is still considered the gold standard for detection of vascular injury due to its spatial resolution, although multi-slice CT is challenging this view. Angiography has the advantage of offering potential therapy at the same time, especially in the case of CCF's.

In 15 of the cases studied, the angiogram provided significant additional information compared to CT head scan. These were 9 cases of retained knives/screwdrivers, 2 cases of false aneurysms, 3 cases of CCF's and one incidental posterior communicating artery aneurysm. The primary value of angiography lies in its ability to exclude significant vascular injury in the setting of CT-detected intracranial haemorrhage.

The optimal time to perform and repeat angiography is not clear. Du Trevou and van Dellen in their study dealing primarily with knife wounds to the head in general, suggest that the angiogram should be performed as soon as possible. In cases of vasospasm, it may be prudent to repeat the study at a later date. The need to perform repeat angiography following a normal study is unclear, but is probably not supported by their data.[1]

Angiography should be performed in at least 2 conventional orthogonal planes. This is problematic when dealing with a retained foreign body such as a knife where the breadth of the object may obscure the vessel in question. Non-standard projections may be required to display the minimum profile of the object "down the barrel"/"along the shaft" and "edge on" to the knife. Additional views may be required to demonstrate the knife tip adequately.

Multidetector CT scanners are now becoming the norm in day-to-day practice and have the ability to produce high quality angiographic images in a matter of minutes with intravenous contrast injections. Although they still lack the resolution of conventional catheter angiography and sometimes suffer from metal artifact, the availability of the modality makes it attractive for safe, easy and (if necessary) repeated assessment of potential vascular injury in these patients.

Magnetic resonance imaging

The role of MRI in this type of trauma is very limited. The modality is not as widely available, is not as quick and is not as compatible with resuscitation equipment as is CT. It is also not able to provide good visualization of bone structures. There is also the risk of unknown metallic objects within the orbit potentially causing blindness when they move under the influence of the MRI machine's magnetic field. As discussed previously, a role in the detection of wooden foreign bodies after negative CT examination is possible.

In this study, one case of CCF demonstrated on MRI would equally have been demonstrated with CT and/or angiography.

Antibiotic use

Of the 48 cases with complete chart data, 13 patients developed meningitis that was treated, 14 received prophylactic antibiotics and 18 received none. Although 10 cases of meningitis developed more than one day after admission, 3 had features suggestive of meningitis earlier and were placed on antibiotics. It is not clear from the data whether any of those on prophylactic antibiotics developed meningitis and required a change of therapy. This subset suggests that 28 cases did not receive prophylactic antibiotics. Of these, 10 (36%) subsequently developed meningitis and required treatment. Of these 10, 6 had risk factors for developing meningitis (pneumocephalus and/or penetration of a paranasal sinus), 1 had no risk factor and in 3 details were insufficient. Even if risk factors had been acted upon, the meningitis rate in those not on prophylactic antibiotics was 18%.

Paranasal sinus involvement, pneumocephalus and infective complications

Of the 19 cases with pneumocephalus, only 6 developed meningitis; case 14 developed a frontal lobe abscess. However, there were a further 7 cases of meningitis that were not associated with pneumocephalus. In this group, one did not involve a paranasal sinus, 2 involved a paranasal sinus and in 4 the records were incomplete. The risk of meningitis following the development of pneumocephalus was 6/19 (32%), compared to 7/34 (21%) for those without pneumocephalus. If the cases with insufficient data are removed, the risk of meningitis following breach of a mucosal surface (pneumocephalus or paranasal sinus involvement) is 38% (8/21) versus 4% (1/28) without a breach. Even if all the excluded cases involved a paranasal sinus or all did not, the risk did not significantly alter, namely 48% versus 16% respectively. It can therefore be assumed that although the risk of developing meningitis is higher with pneumocephalus, there is still a significant baseline risk. Prophylactic antibiotics may therefore be advisable, although there is no consensus in the literature.[2(pp78-79), 15, 50]

Cerebrospinal fluid fistulae

Of the 4 cases with a CSF leak, all had pneumocephalus, 2 settled spontaneously and 2 required anterior cranial fossa repairs for persistent leak. Only 1 presented with meningitis. Two received prophylactic antibiotics and one did not. The incidence of this complication is too low to make meaningful comparisons with published figures.

Anticonvulsant usage

Of the 47 cases with sufficient data, 5 received therapeutic anticonvulsants, 13 were given prophylactic anticonvulsants and 29 did not receive any. This suggests that 34 were initially not given prophylactic anticonvulsants. Of these, only 5 (15%) subsequently developed seizures and required treatment.

Seizures

Of the 5 cases with seizures, 2 (cases 18 and 46) only developed them by 3 years after injury. Both these cases had significant intracranial vascular injury. Due to the incomplete follow-up data, it is not possible to determine the true incidence of seizures following this type of injury.

Vascular complications

In a total of 70% (37/53) of cases, some form of vascular injury was evident on imaging. Most vascular injuries were evident on CT and/or angiography. The commonest findings were ICH and CCF. This is higher than the approximately 50% incidence described in the literature.[15, 16, 18]

The 6 cases of SDH and 13 of SAH in this study are significant, as there have only been 2 previously described similar case reports.[50, 57] This higher incidence is thought to be a consequence of the greater use of CT in evaluating these injuries.

Two false aneurysms were identified (cases 4 and 16). As 75% (40/53) of cases had an angiogram performed, this does not explain the low incidence (4%) in comparison with previously published rates of between 15 and 20%.[15, 16, 18] Both cases occurred in the setting of intracranial haemorrhage initially demonstrated on CT. Both had an ICH and one each had an IVH and SDH. Excluding one death, all but 2 cases of CT-detected intracranial haemorrhage had an angiogram performed. One false aneurysm was only detected on follow-up angiography. The reason for a repeat study after an initially normal investigation could not be determined from the patient notes. It is the possible that some of the CCF cases may have initially represented cavernous carotid false aneurysms that subsequently ruptured, creating the fistula. This follows on the assumption that CCF and traumatic false aneurysm are a continuum of the same arterial injury.[76]

As discussed above, 8 of 14 cases of CCF presented more than 5 days following injury. The longest interval was 4 years. There were no deaths in the current series, although the outcome of 2 potentially untreated cases is not known. This finding is similar to previous local publications.[2(p49), 16, 36]

The 3 cases of infarction were all associated with permanent neurological deficit.

Although intracerebral haemorrhage or knife tracks have been reported on CT in previous publications, these were not discussed in detail. As expected following orbital penetration, these involved mainly the frontal and temporal lobes in isolation or combination. Intraventricular haemorrhage occurred in 5 cases and in all but one were an extension from an adjacent ICH. The 2 deaths (cases 8 and 36) both had IVH.

Neurological complications

A total of 32 cases had a normal GCS of 15 at presentation. Of the 11 cases with a significantly depressed level of consciousness with a GCS less than 13/15 at presentation, no dominant aetiology was discernable.

A total of 14 cases had neurological deficit at presentation. Three of these resolved spontaneously. Of the remaining 11, all but one (case 3, meningitis and aphasia) were associated with vascular injury.

Orbital and visual complications

There were no bilateral or contralateral injuries. One case (case 42) had a pre-existing blind eye due to a post-traumatic cataract and was therefore bilaterally blind following the assault. A total of 24 cases that involved eyes were blind at discharge. Ten of these were due to surgical evisceration. The commonest cause for a blind eye was disruption of the globe (9/16) during the assault, followed by carotico-cavernous fistula (6/14) and presumptive optic nerve injury (5/5). Optic nerve injury was presumed in cases where there was CT evidence of optic nerve disruption, or compromise by an adjacent bone fragment, or visual acuity of NPL together with a TAPD, but no globe disruption.

Of the 33 cases without globe injury, 17 had an abnormal visual acuity (CF, HM, PL or NPL). This was though to be due to varying degrees of lesser (non-disruptive) injury to the globe and optic nerve. As the visual acuity was almost never assessed at discharge and few patients returned for ophthalmological follow-up, it is not known whether this finding was transient or permanent.

Morbidity

Only 7 cases (13%) had no complications. Eleven cases (21%) had persistent neurological deficits. The involved eye was blinded in 45% of cases. As 57% of cases did not return for follow-up, the true incidence of morbidity and mortality for this study group is unknown.

Mortality

There was only 4% (2/53) mortality in this study. This is considerably lower than the 13% (16/129) overall average and 44% (37/84) due to assault reported in the literature between 1977 and 1997.[2(pp92, 114)] Even previous local studies from the same institution as this study had mortalities of around 30%.[15-17] It is difficult to speculate on the reason for this. It is assumed that recognition of the injury and timeous transfer to hospital have not changed significantly over the last 20 years. More rapid transfer might even result in more cases surviving long enough to reach hospital before expiring, whereas longer delays could result in deaths prior to hospital admission. The current investigation of suspected orbital injury invariably includes a CT head; this was not available 2 decades ago. This would be more sensitive to pneumocephalus than a skull radiograph. Also, other findings such as subarachnoid blood and focal haemorrhage may not have been detected by clinical or angiographic means. However, assuming CT was not available, excluding cases that would have had a normal skull radiograph, having a normal clinical neurological examination or cerebral angiography (cases 2, 5, 7, 19, 38, 42, 51) does not significantly alter the mortality rate. Improvements in management might account for the difference, with local experience in dealing with these injuries possibly improving outcomes.

Follow up after discharge

The overall follow-up rate following discharge was only 43%. As might be expected, the only cases that returned for long-term follow up had significant residual morbidity.

SUMMARY

Confirmation of published data

This study confirms that this type of injury is relatively uncommon, occurs predominantly in young males, involves mainly the left eye (often the upper and medial portions) and has significant associated morbidity. Almost half the cases will be blinded in the affected eye. Those that present with a retained object tend to have a better prognosis than those where the assailant has already removed the penetrating instrument. Vascular injuries are common and are strongly associated with both death and permanent neurological deficit. Delayed presentations are usually brought about by the development of CCF and meningitis. The association between paranasal sinus involvement, pneumocephalus and meningitis is reaffirmed.

New data and suggestions raised by this study

A CT of the brain and orbits should be performed in all cases of confirmed or suspected penetrating orbital trauma. A skull radiograph is of little value. All cases of retained objects, those with features of haemorrhage or CCF on CT, features of intracranial penetration such as pneumocephalus, or neurological abnormality should undergo angiography. In the initial trauma setting, a CT angiogram might be quicker and easier to perform in all cases and should be able to exclude significant arterial injury in place of or prior to conventional angiography. A conventional angiogram would be able to detect any false aneurysm missed on CT. In cases with vasospasm, it may be prudent to repeat the angiogram at a later date.

The lower mortality in this study group when compared to other series is difficult to explain, but may be related to more effective diagnosis and recognition of complications using early CT investigation.

Approximately 36% of cases that did not receive initial prophylactic antibiotics and 15% not receiving prophylactic anticonvulsants subsequently required them. Whether this should alter management is speculative.

Unanswered questions

Comparisons between CT angiography and conventional angiography will be required to determine whether CT angiography is sufficiently sensitive to be used in preference to angiography in certain cases, or as a screening tool prior to further endovascular management.

Most of the CT investigations performed in this study concentrated on the brain rather than specifically the orbits. As there is currently no proven treatment for traumatic optic neuropathy, the inclusion of dedicated fine slices through the orbits to identify other causes for visual impairment such as compression from bone fragments appears to be of little value.[77]

CONCLUSION

All patients with a suspected transorbital injury should have a CT head performed to assess for intracranial injury. A skull radiograph is of no value. Due to the high incidence of vascular injuries, a conventional angiogram should be performed in all cases of intracranial penetration. A CT angiogram may be of value in the initial setting to exclude a major vascular injury. Prophylactic antibiotics and anticonvulsants may offer some protection. Despite adequate treatment, the neurological and visual outcome for many of these patients is poor.

FIGURES OF REPRESENTATIVE CASES

Figure 1 (A): Case 4. Uncontrasted axial CT brain demonstrating left frontal lobe knife track containing acute haemorrhage (white arrow) and air (single arrow).

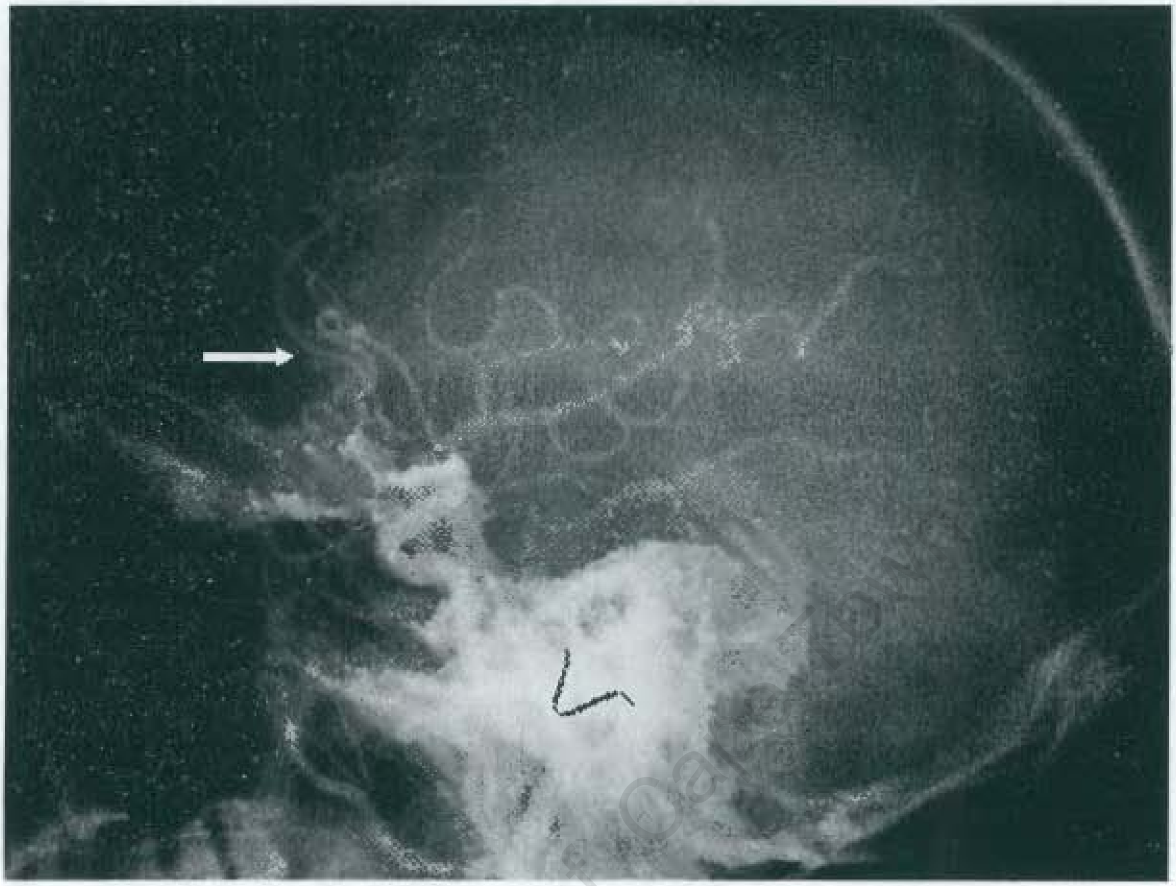


Figure 1 (B): Case 4. Left common carotid angiogram demonstrating small false aneurysm arising from the A2 segment of the left anterior cerebral artery (white arrow).

Figure 2 (A): Case 23. Axial T1-weighted MRI demonstrating flow voids in dilated right superior ophthalmic vein (white arrow) consistent with a CCF. Previous left enucleation noted (single arrow).

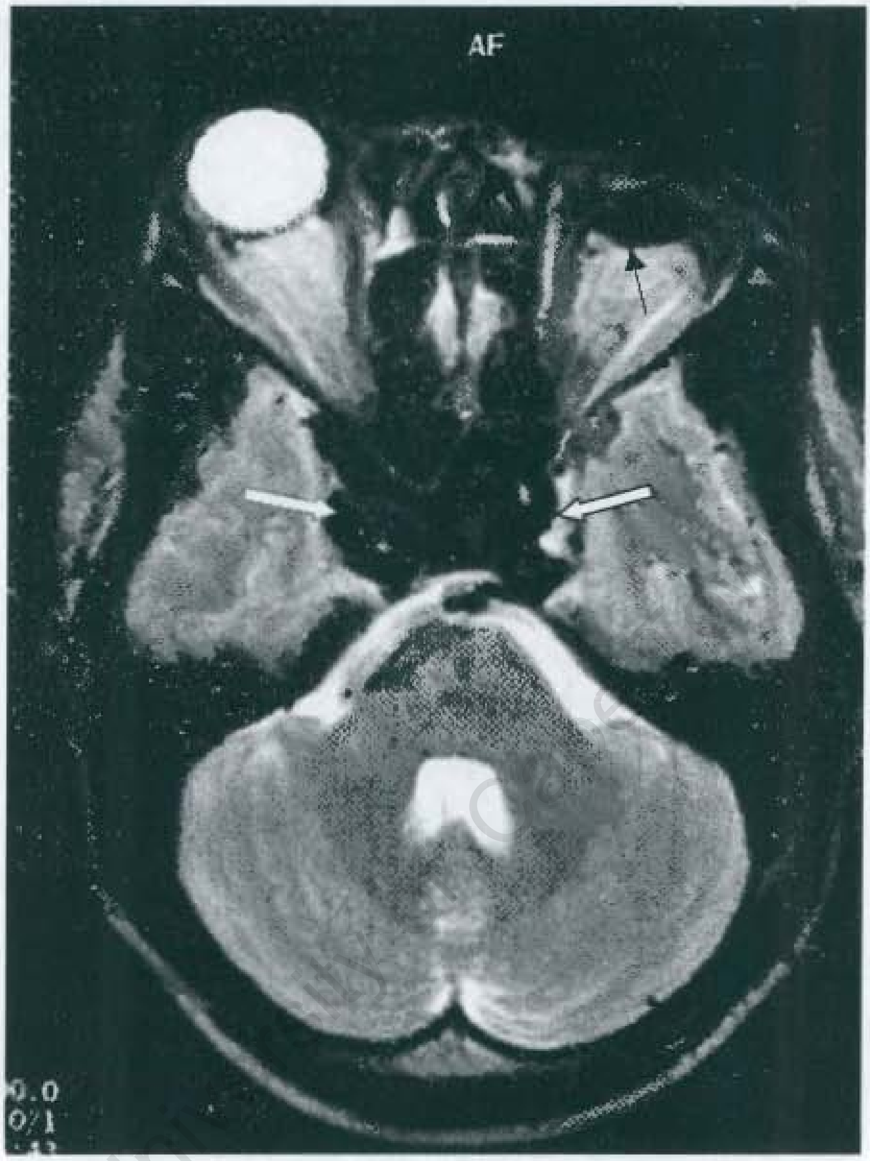


Figure 2 (B): Case 23. Axial T2-weighted MRI demonstrating flow voids in dilated cavernous sinuses (white arrows) consistent with a CCF. Previous left enucleation noted (single arrow).

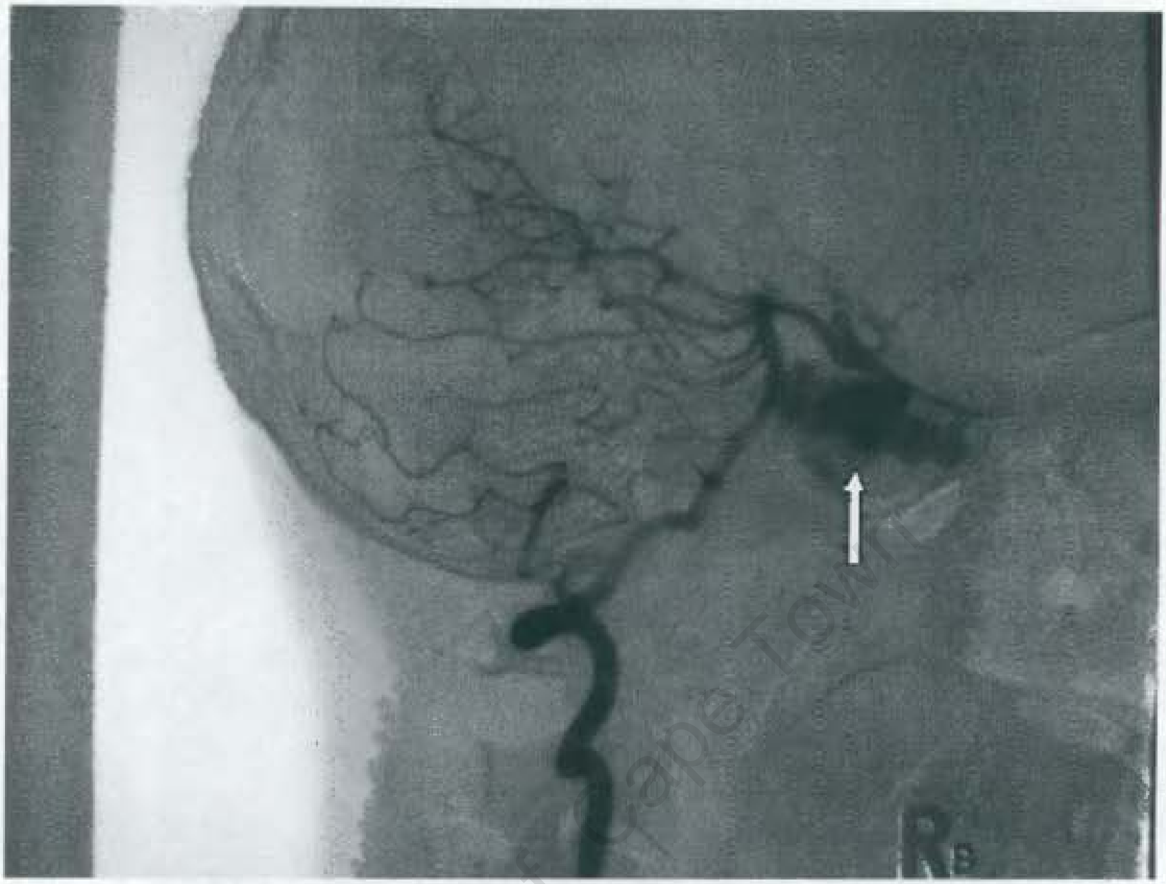


Figure 2 (C): Case 23. Right vertebral angiogram demonstrating flow into CCF (white arrow) via the right posterior communicating artery. This is a useful angiographic technique to demonstrate the exact site of the opening when there is a high flow rate fistula between the internal carotid artery and cavernous sinus.

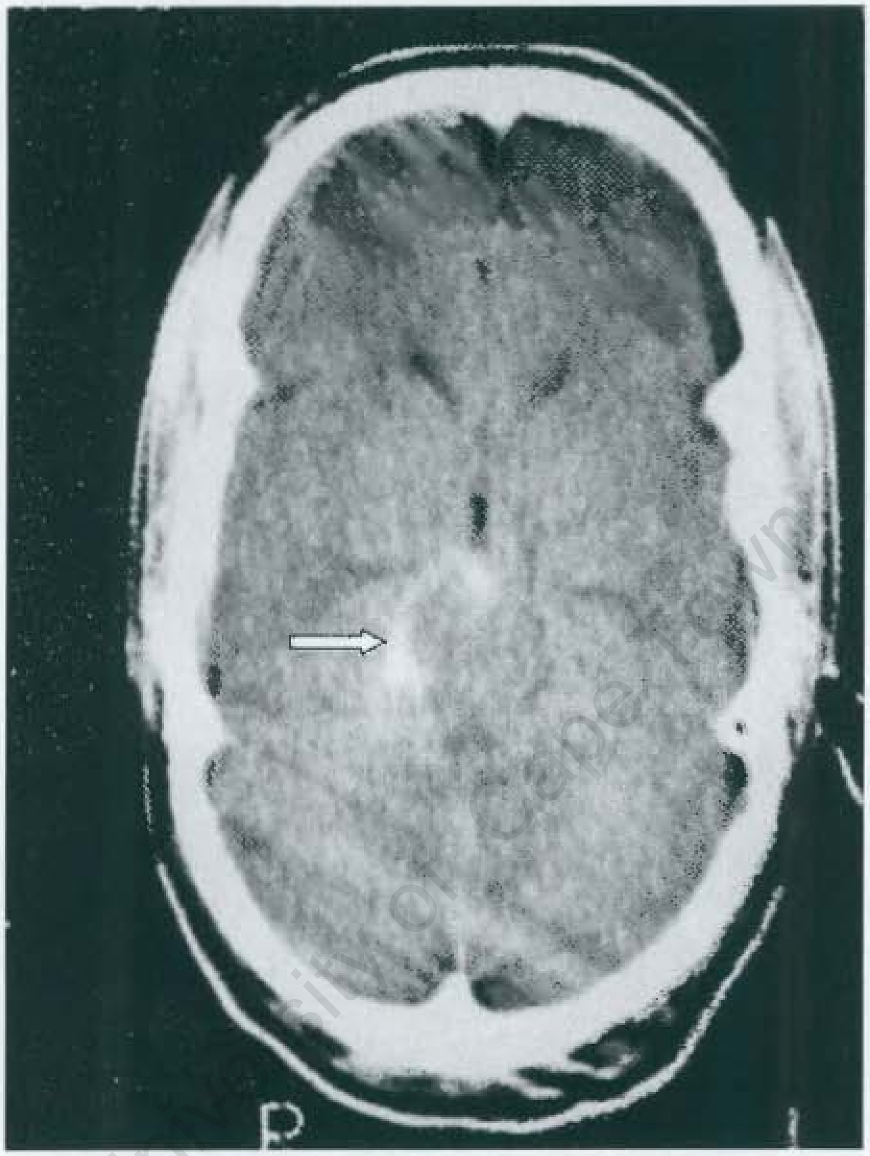


Figure 3 (A): Case 31. Axial CT of the brain without contrast demonstrating subarachnoid blood (white arrow) filling the prepontine and ambient wing cisterns.

Figure 3 (B): Case 31. Uncontrasted axial CT of the brain (bone windows) demonstrating the metal streak artifact (single arrows) surrounding the tip of the retained knife (white arrow).

Figure 3 (C): Case 31. Left common carotid angiogram in frontal and lateral views. No injury present. Note the technique to demonstrate the most minimal viewable surface of the retained knife.

Figure 3 (D): Case 31. Right common carotid angiogram on frontal and lateral views. No injury present. Note the projection used to minimize the obscuring effect of the retained knife.

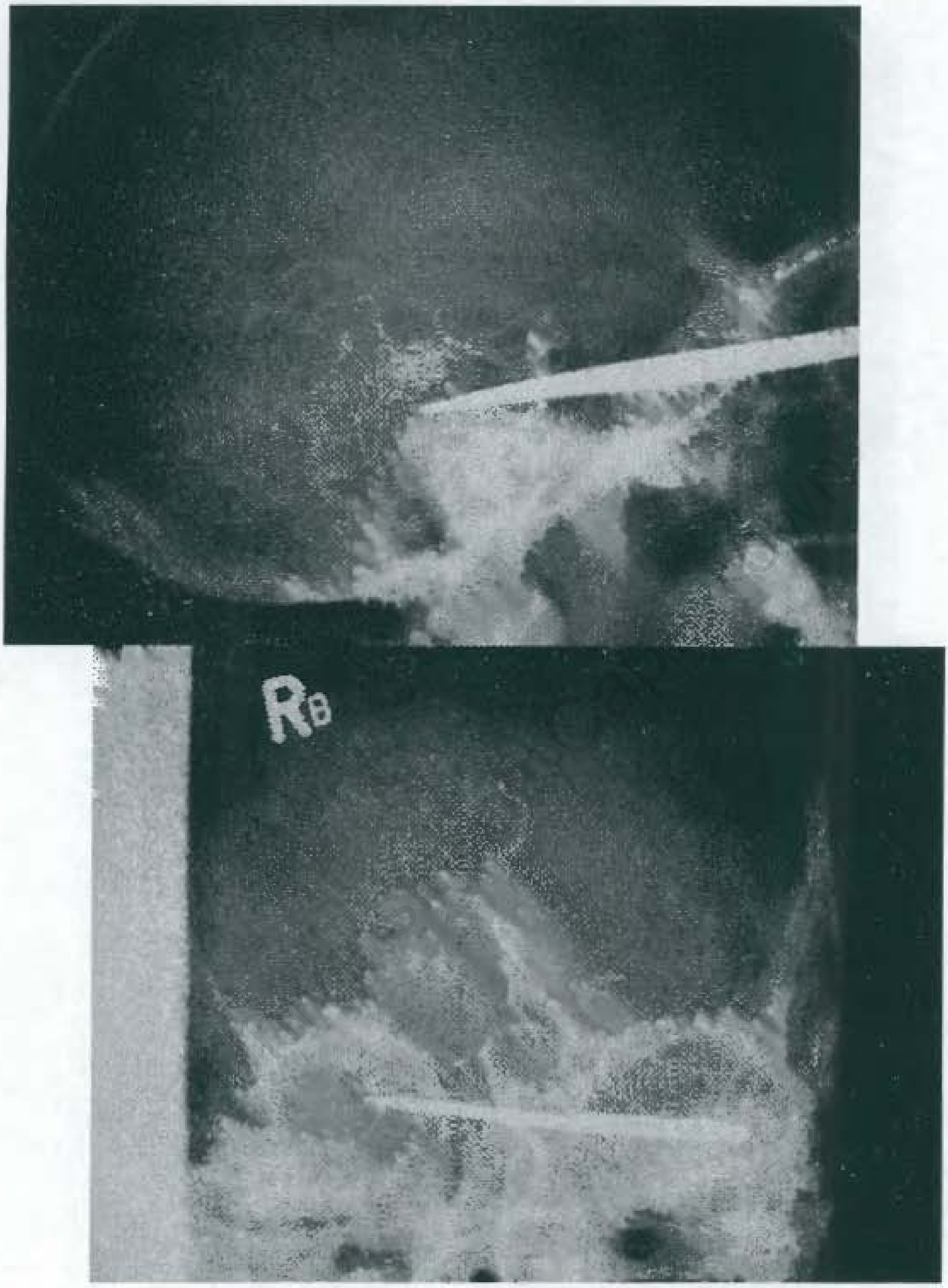


Figure 3 (F): Case 31. Right vertebral angiogram in lateral and frontal views. No injury present. Note the technique to demonstrate the minimal viewable surface of the retained knife.

Figure 4 (A): Case 33. Axial CT brain (bone window) demonstrating the knife track and fracture through the right posterolateral orbital wall (white arrow).

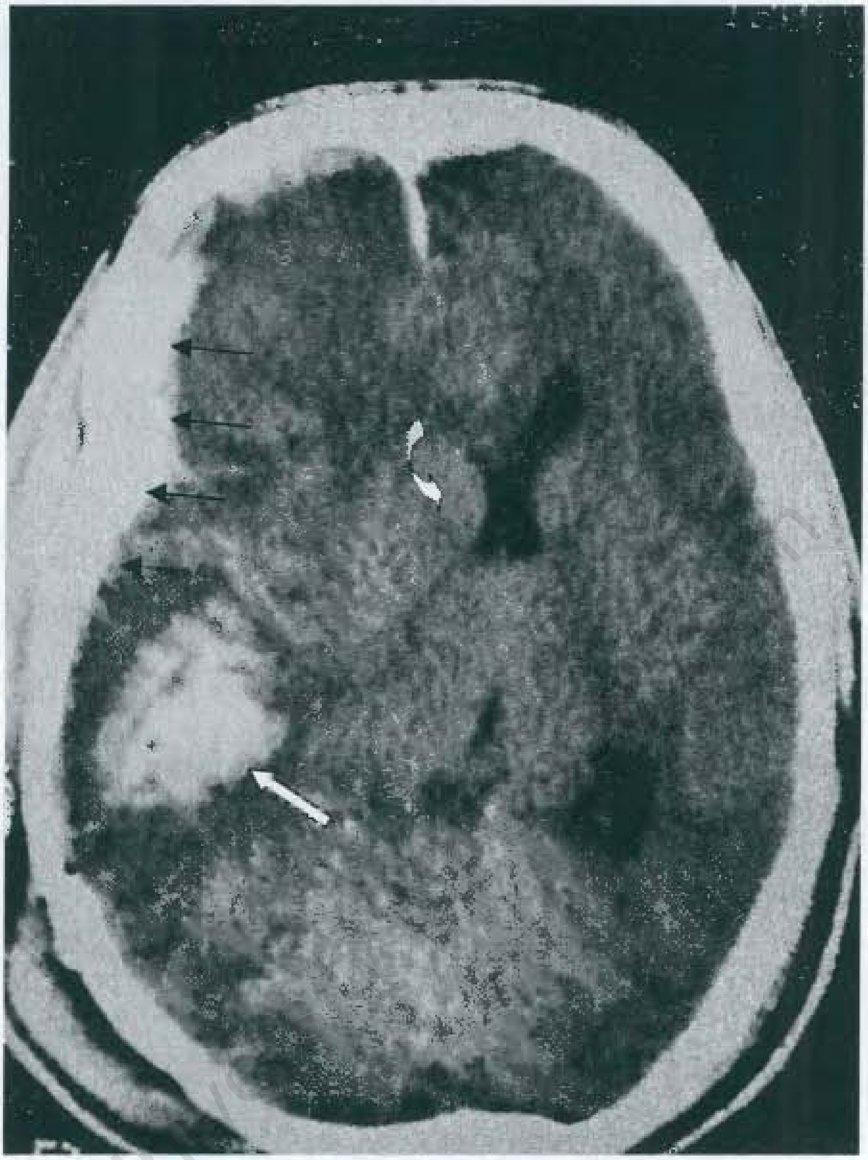


Figure 4 (B): Case 33. Axial CT brain demonstrating the acute right temporal lobe intraparenchymal haemorrhage (white arrow) and overlying right subdural haemorrhage (single arrows). Note also the mass effect with midline shift to the left (curved arrow).

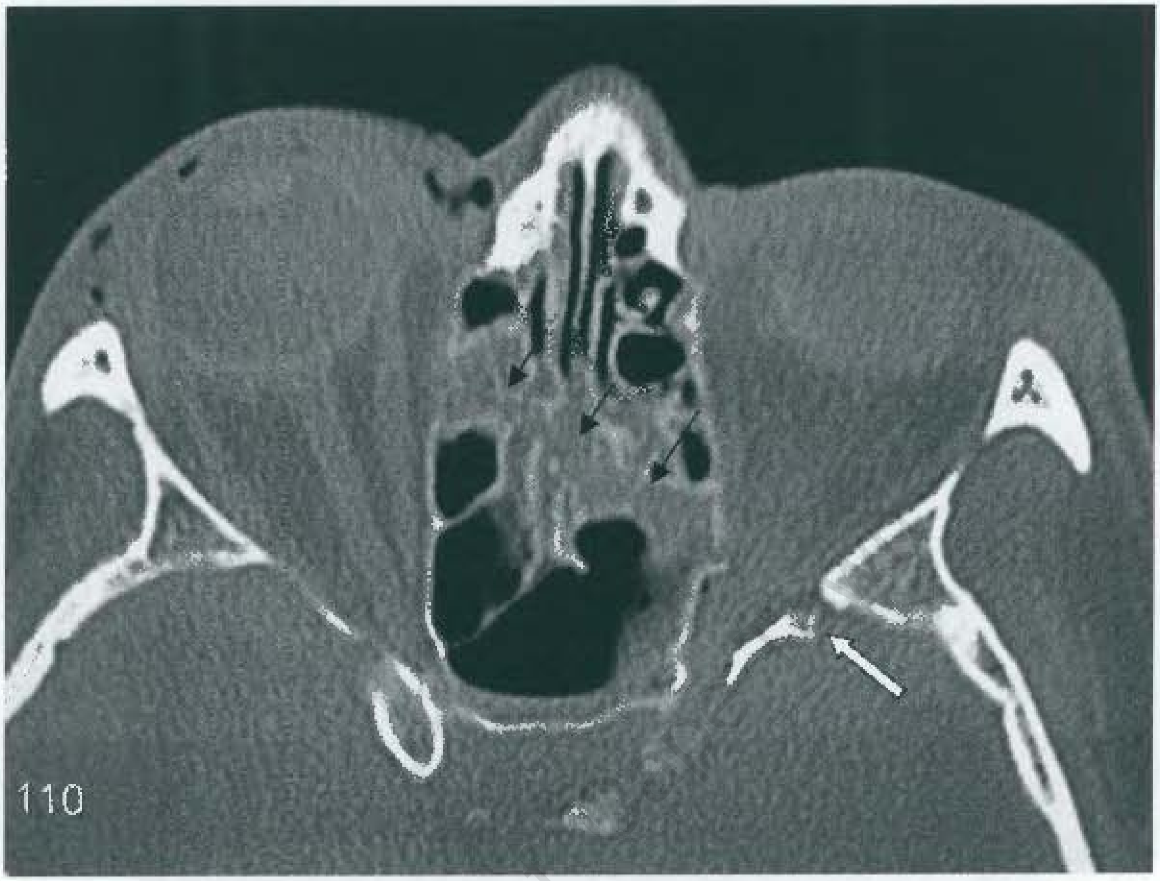


Figure 5: Case 38. Axial CT brain (bone windows) demonstrating knife track (single arrows) through both ethmoid air sinuses, as well as a fracture involving the posterolateral wall of the left (contralateral) orbit (white arrow). Further cranial slices demonstrated pneumocephalus.

Figure 6 (A): Case 44. Frontal skull radiograph demonstrating knife retained in situ.

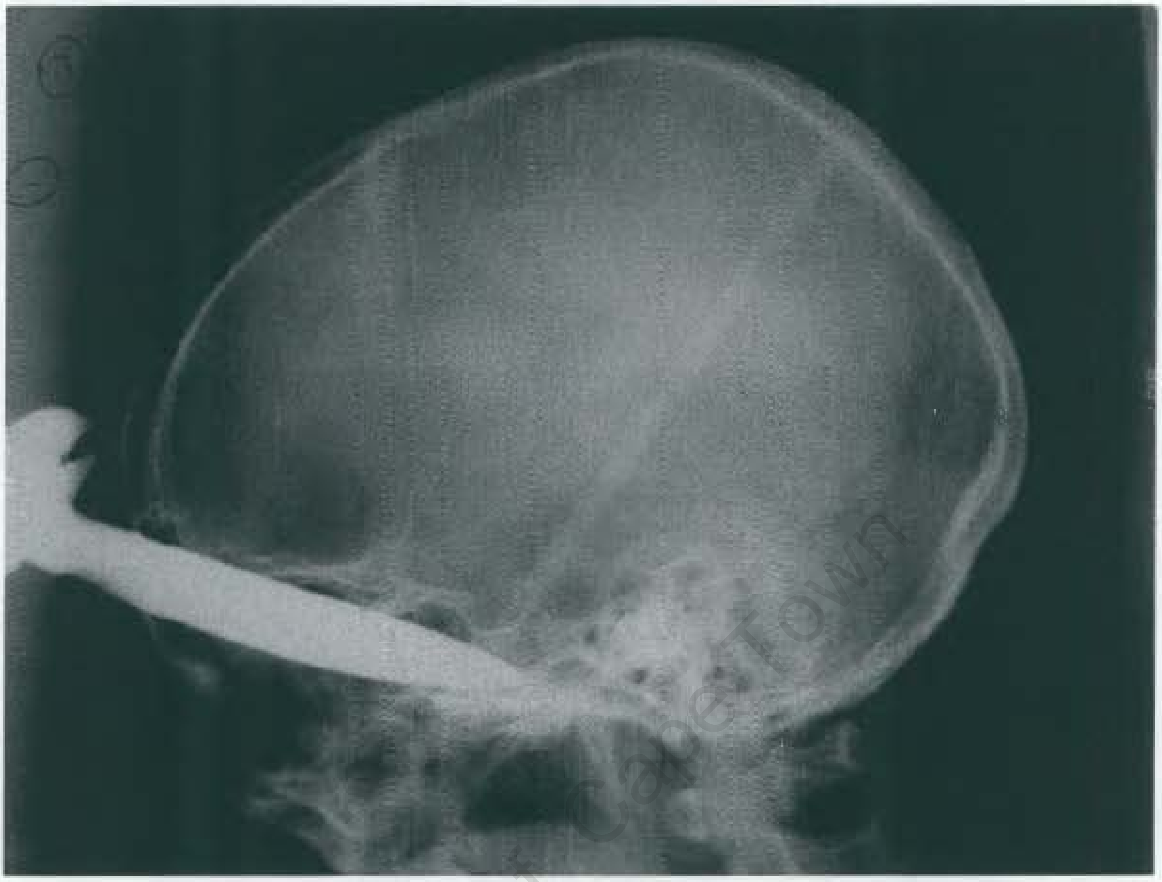


Figure 6 (B): Case 44. Lateral skull radiograph demonstrating knife retained in situ.

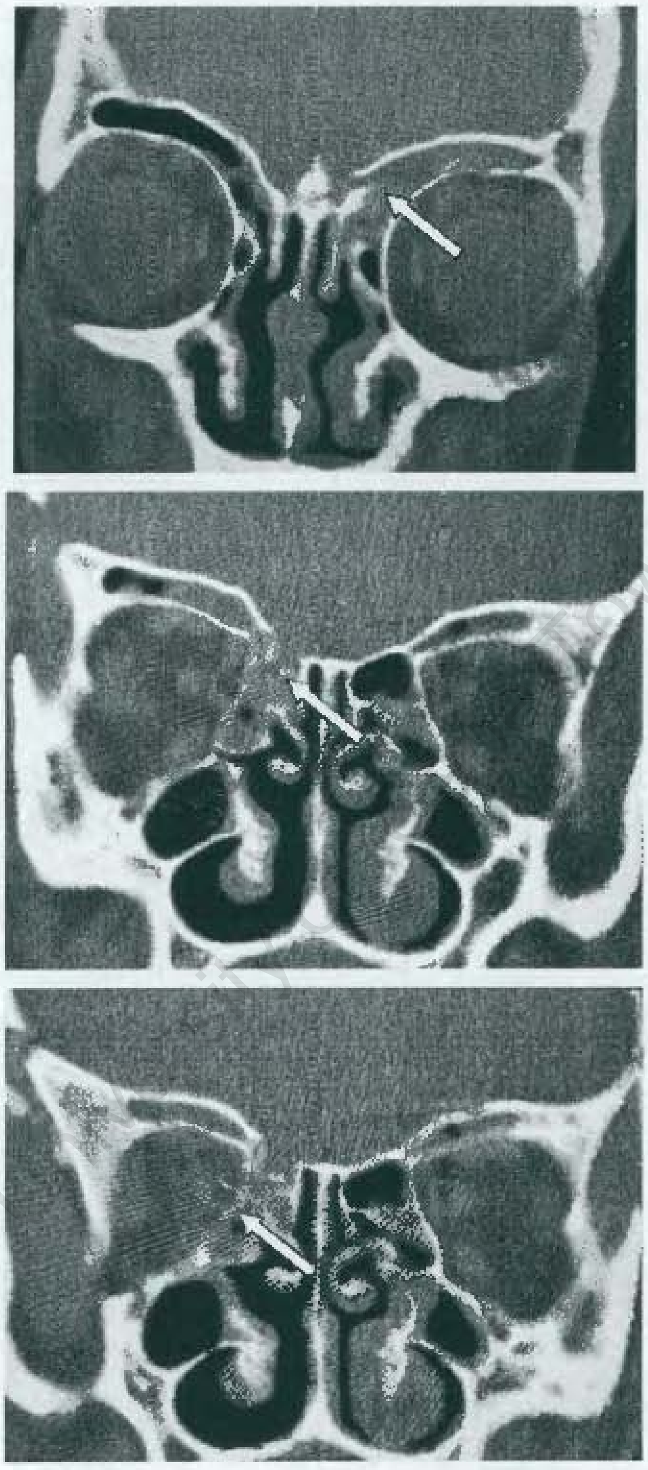


Figure 6 (C): Case 44. Following extraction of knife. Montage of 3 coronal CT slices (from anterior to posterior) of the anterior cranial fossa demonstrating the knife track (white arrow).

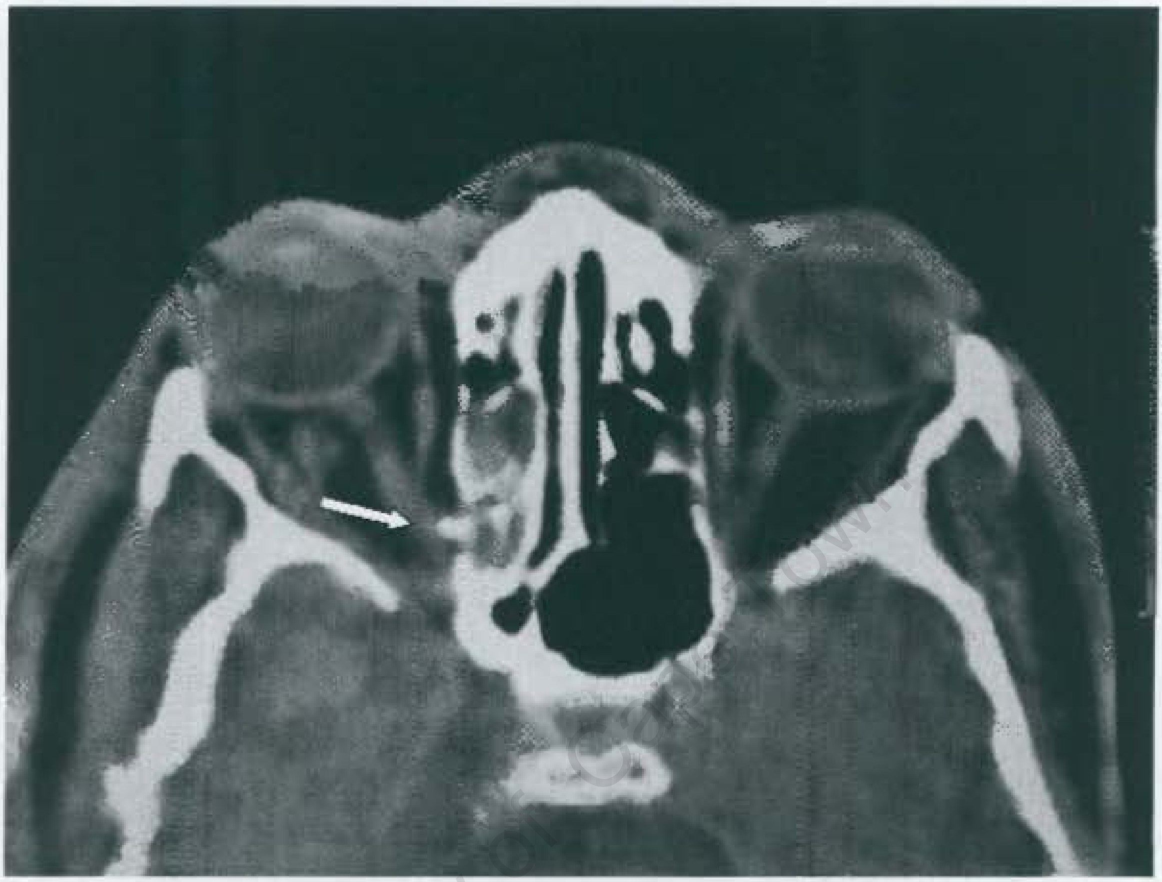


Figure 6 (D): Case 44. Axial CT of the orbits demonstrating the bone fragment (white arrow) impinging on the right optic nerve. The right globe was intact.

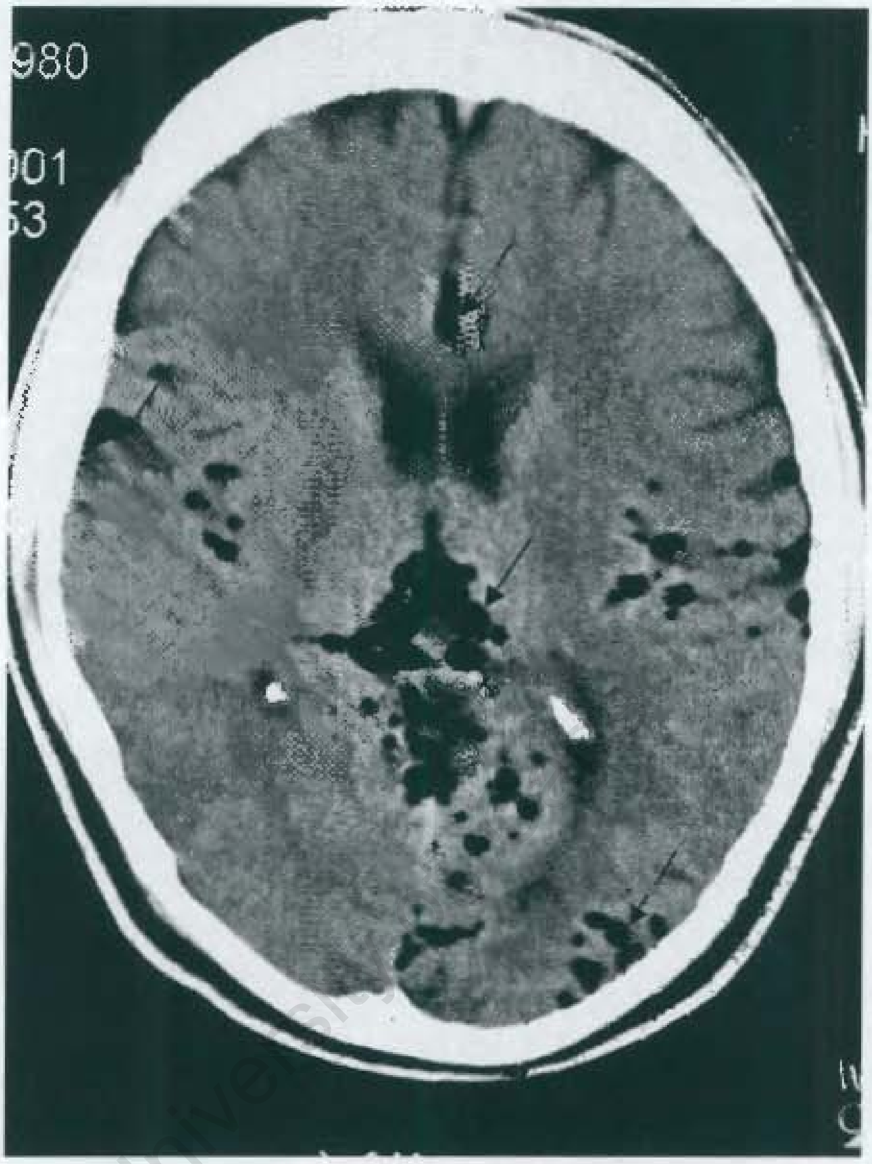


Figure 7: Case 51. Axial CT of the brain demonstrating extensive pneumocephalus (single arrows).

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APPENDIX

Demographics and basic data.

Case No.	Age	Sex	Side	Stab site	Instrument	Retained	Delay before admission(s) in days unless stated	Pathology	Complications
1	36	M	L	Eye	Knife	No	0/45	L CCF	Vascular, visual
2	19	M	L	Lateral/upper	Knife	No	1	Pneumocephalus	Seizures, neurological
3	23	M	L	Medial canthus	Knife	No	2/86/163	Meningitis, pneumocephalus	Infective, neurological
4	17	M	L	Lateral to lateral canthus	Knife	No	0	L ICH, L SDH, L A2 FA, pneumocephalus, SAH	Vascular
5	22	F	L	Supraorbital	Knife	No	0	SAH	Visual
6	25	M	R	Upper lateral orbit	Knife	No	1	Meningitis, pneumocephalus	Infective, visual
7	35	M	R	Eye/glabella	Screwdriver	No	0	R cut optic nerve, pneumocephalus	Visual
8	25	M	L	Lateral	Knife	No	1	Pneumocephalus	Infective, vascular, death
9	35	M	R	Upper lateral lid	Knife	No	0	ICH, meningitis, SAH	Vascular, infective, visual
10	22	F	R	Upper lid	Knife	No	0/5	L CCF	Vascular, visual
11	23	M	L	Upper lid	Knife	No	0	CSF leak, ?pneumocephalus	Visual
12	27	M	L	Eye	Knife	No	0	IVH, ICH (L temporal pole), meningitis	Infective, visual
13	28	M	L	Medial upper + lower lid	Knife	No	0	ICH (L frontal)	Vascular
14	20	M	R	Eye	Knife	Yes	0	Pneumocephalus, abscess (R frontal)	Infective, visual
15	35	M	R	Lid	Knife	No	1	CCF	Vascular
16	32	M	L	Lateral lid	Knife	No	0	FA, meningitis, ICH, IVH, SAH	Infective, vascular, visual, neurological, seizures
17	32	M	L	-	Knife	Yes	0	Retained, infarct, ICH	Vascular, neurological
18	57	M	R	Medial eyebrow	Knife	No	0	ICH (R temporal pole), SAH	Vascular, seizures
19	26	M	L	Lateral	Knife	No	0	Pneumocephalus	None
20	23	M	L	Upper lid	Knife	No	0	ICH (L frontal), meningitis	Vascular, infective
21	25	M	L	Upper medial canthus	Knife	No	0	ICH (L)	Vascular, visual
22	35	M	L	Upper medial lid	Knife	No	0	CSF leak, pneumocephalus	None
23	22	M	L	Eye	Knife	No	4 months	R CCF	Vascular, visual
24	22	M	L	Upper medial canthus	Knife	Yes	0	Retained	None
25	25	M	R	Eye	Knife	No	3 years	R CCF	Vascular, visual

26	26	M	L	Eye	Knife	No	-	R CCF	Vascular
27	23	M	L	Eye	Knife	No	0	SAH, infarct (L PCA)	Vascular, visual, neurological
28	23	M	R	Eye	Knife	No	-	R CCF	Vascular
29	17	M	L	Eyebrow	Knife	No	0/7	L CCF	Vascular, visual
30	39	M	L	Eye	Knife	No	-/-	L CCF	Vascular, visual
31	29	M	L	Eye	Knife	Yes	0	Retained, SAH	Neurological, visual
32	23	M	R	Medial eye	Knife	No	0	ICH (R), pneumocephalus, ? optic nerve cut	Visual
33	32	M	R	Lower lid	Knife	No	0	ICH (L), SDH (L frontal)	Vascular, visual, neurological
34	21	F	R	Eye	Knife	No	-/4 years	SAH, R CCF, ICH, IVH	Vascular, neurological
35	26	M	L	Eye	Screwdriver	Yes	0	Retained, knife track	Neurological, seizures
36	36	M	R	Upper lid	Knife	No	0	ICH, SAH, IVH	Vascular, death
37	20	M	R	Eye	Screwdriver	No	-	Pneumocephalus, meningitis	Infective
38	40	F	R	Supraorbital	Screwdriver	No	0	Pneumocephalus	None
39	43	M	L	Eye	Knife	Yes	0	Retained	Visual
40	36	F	L	Eye	Knife	No	3/3 months	L CCF	Vascular, visual
41	41	M	R	Eye upper lid	Knife	No	0	Meningitis	Infective, visual
42	40	M	L	Medial orbit	Knife	No	8	ICH, pneumocephalus, SDH	Visual
43	19	M	L	Medial lower lid	Knife	No	I	ICH (L)	Infective, visual
44	23	M	L	Supraorbital	Knife	Yes	0/27	Retained, SDH, meningitis, R optic nerve injury	Vascular, infective, visual
45	22	M	L	Eye	Knife	No	-	Meningitis, pneumocephalus	Infective
46	26	M	R	Medial orbit	Knife	No	0	SDH, ICH, pneumocephalus	Vascular, neurological, visual, seizures
47	54	M	L	Eye	Knife	No	1 week	R CCF	Vascular
48	20	M	L	Lower lateral orbit	Knife	Yes	0	Retained	None
49	28	F	R	Medial orbit	Knife	Yes	0	Retained	None
50	29	M	L	Upper lid	Knife	No	0	L CCF, infarct, SAH	Vascular, neurological
51	21	M	L	Upper lid	Knife	No	0	Pneumocephalus	None
52	26	M	R	Eyebrow	Gemsbok horn	No	2 weeks	R CCF	Vascular, visual
53	34	M	L	Supraorbital	Knife	Yes	0	Retained, pneumocephalus, ICH (R)	Vascular, visual

Ocular and neurological status data.

Case No.	Globe injury	Visual loss	APD	Eye movements	GCS	Clinical and Neurological features
1	No	CF	RAPD 2+	Decreased esp VI	15	L VII palsy
2	No	CF	RAPD 3+	Decreased	15	Normal
3	No	-	-	-	8	Meningitis
4	No	Normal	No	Decreased	14	Normal
5	Yes	PL	RAPD 3+	None	15	Normal
6	No	NPL	RAPD	-	10	Normal
7	No	NPL	RAPD	None	15	Tense orbit
8	Yes	NPL	TAPD	None	15	R temporal field loss
9	Yes	NPL	RAPD	-	13	Normal
10	Yes	NPL	TAPD	-	15	L proptosis + bruit
11	Yes	PL	RAPD	Ptosis	15	Normal
12	Yes	NPL	-	-	13	R hemiplegia
13	No	Normal	No	Normal	12	Mild R hemiplegia and aphasia
14	Yes	NPL	-	-	-	-
15	No	PL	RAPD	-	15	-
16	No	NPL	TAPD	-	11	Normal
17	-	-	-	-	15	Normal
18	No	6/60	RAPD	Ptosis	-	? R III + VI nerve palsy
19	No	6/15	No	Normal	15	Normal
20	No	HM	RAPD	Decreased	15	Normal
21	No	NPL	RAPD	None	14	Aphasia (resolved)
22	No	6/7.5	No	Normal	15	CSF leak
23	Yes	R Normal, L evisc	-	Normal	-	R proptosis + bruit
24	No	6/7.5	-	Normal	15	Normal
25	No	NPL	-	Decreased	15	R proptosis + bruit
26	-	-	-	-	-	-
27	No	NPL	TAPD	None	6	R hemiplegia
28	Yes	NPL	TAPD	None	15	R proptosis + bruit
29	No	6/36	RAPD 2+	None	15	L proptosis + bruit
30	Yes	R HM, L evisc	-	None	15	R proptosis + bruit
31	Yes	NPL	TAPD	-	11	L hemiplegia
32	No	NPL	RAPD 3+	None	15	Normal
33	Yes	R NPL	-	-	5T	Normal
34	No	-	-	-	9A	L hemiplegia + aphasia + L Weber Syndrome
35	No	Normal	-	-	15	Delayed 6 + 7 palsy
36	Yes	NPL	TAPD	-	5	Decreased level of consciousness
37	No	CF	-	-	15	-
38	No	CF	No	Decreased	15	Normal
39	Yes	NPL	TAPD	None	15	Normal
40	-	NPL	-	-	15	Bilateral proptosis + bruit
41	Yes	NPL	TAPD	None	14	Normal
42	No	NPL	RAPD	None	15	R cataract (previous blunt trauma)
43	No	6/18	RAPD	Decreased	15	Meningitis
44	No	-	-	-	6T	Normal/meningitis
45	-	-	-	-	-	-
46	No	CF	No	None	14 to 5	Normal to L hemiplegia
47	No	Normal	No	Normal	15	R proptosis + bruit

48	No	Normal	No	Normal	15	Normal
49	No	Normal	No	Normal	15	Normal
50	No	NPL	TAPD	Decreased	15	Day 8 deterioration with R proptosis and bruit
51	Yes	6/18-2	NO	Normal	15	R upper limb monoplegia (resolved spontaneously)
52	No	NPL	RAPD 3+	None	15	R proptosis – bruit
53	No	Normal	No	Normal	15	Normal

Imaging findings data.

Case No.	SXR	CT (and MRI for case 23)	Angiography	Time from admission to angiography in days (time from injury)
1	Normal	L CCF (L proptosis, dilated L SOV, L cavernous sinus bulge)	L CCF (arises lower siphon, drains to L SOV+petrosal sinus+IJV, good crossflow)	2 (46)
2	L orbit roof fracture	Pneumocephalus, bone fragment in frontal lobe	Not done	-
3	L ethmoid opacification, ventricular air	Fracture L superior orbit margin+L lamina papyracea+ethmoid+R sphenoid body+R cribriform plate, bone fragments in frontal sinus, air in basal cisterns and ventricles	Not done	-
4	-	Fracture L frontal bone+ACF floor, SAH, L parietal SDH, L frontal ICH track with air	L A2 false aneurysm	10
5	-	SAH, mild hydrocephalus	Normal	3
6	Normal	R temporal SDH, small pneumocephalus, fracture R posterior cribriform plate+both planum sphenoidale+frontal/ethmoidal sinuses	Normal	18
7	-	Fracture R frontal sinus+R lamina papyracea+R lateral orbit apex+ ethmoid+GWS, ?transected optic nerve, bone fragments in frontal sinus, opacification R frontal, ethmoid, sphenoid, maxillary sinuses	Spasm of R proximal ophthalmic artery	12
8	Pneumocephalus	Pneumocephalus, IVH, SAH	Not done	-
9	Normal	disrupted R globe, fracture R lamina papyracea, L subfrontal/caudate nucleus ICH, SAH,	Normal (incidental duplex A1)	5
10	Normal	Bilateral proptosis, opacified sphenoid+ethmoid sinuses, ?fracture R orbital roof, both cavernous and pontine sinuses distended	L CCF (drains to L SOV+superior/inferior petrosal sinuses+pontine sinus+petrosal sinus+IJV)	8
11	-	Fracture R ethmoid+cribriform plate, L frontal pneumocephalus, distorted L globe with air+haematoma in orbit	Not done	-
12	Fracture L superior orbital roof	L globe haematoma, fracture L orbital roof/apex, L temporal pole haematoma decompressed into L lateral ventricle + basal ganglia	Supraclinoid L ICA spasm	16
13	-	L frontal fracture into sinus, pneumocephalus, L frontotemporal ICH, transsphenoid frontal lobe herniation	L MCA distorted by haematoma	Admission
14	Knife in L orbit, tip in cavernous and sphenoid sinus region	Pneumocephalus, followup CT showed a R frontal lobe abscess, which eventually resolves	Normal (including repeat)	Admission
15	-	Normal	CCF	-
16	Normal	SAH, IVH, ICH	Normal (1st), FA (2nd)	6,24
17	Retained knife	Pneumocephalus, Haemorrhagic infarct	Infarct	Admission

18	Normal	R proptosis, fracture R lateral wall orbit + GWS, small R temporal fossa haematoma, thin R SAH, (R basal ganglia infarct post aneurysm clipping)	Incidental R Posterior communicating artery aneurysm	2
19	-	Pneumocephalus	Not done	-
20	-	L frontal bone + sphenoid wing fracture, L ethmoid fluid, L frontal haematoma	-	-
21	Slot fracture posterior wall L orbit	L proptosis, L orbital haematoma, posterolateral orbital wall slot fracture, L temperoparietal haematoma track	Elevated L MCA from haematoma, incidental hypoplastic L A1	17
22	-	Pneumocephalus, fracture L lamina papyracea extending into cribriform plate	-	-
23	Normal	L enucleation, R CCF with flow voids in R orbit and both cavernous sinuses, dilated R SOV + facial vein, possibly dilated sphenoparietal sinuses	R CCF (which also fills L cavernous sinus), drains to pterygoid plexus + basal vein of Rosenthal, petrosal sinuses, ophthalmic veins, good crossflow	3 (4 months)
24	Retained knife via medial aspect of L orbit into L ethmoid with tip embedded in basisphenoid	Knife track as for SXR, no brain injury	Normal	Admission
25	-	-	R CCF, dilated R ICA, poor filling R ACA + MCA	- (3 years)
26	L ethmoid + maxillary sinus opacification	Normal (maxillary sinus not included on scan)	R CCF, arises at upper C3 (proximal to Ophthalmic artery), drainage to superior ophthalmic vein + pterygoid sinus	-
27	Normal	Traumatic SAH, L proptosis, L retrobulbar haematoma, L PCA infarct, early hydrocephalus, ? L Optic nerve cut	P1 + P2 spasm ?thrombus	16
28	-	-	R CCF with ? transected ICA	-
29	Normal	Fracture L lamina papyracea, L posterior ethmoid opacification, L superior ophthalmic vein + cavernous sinus distended	L CCF, drains to L superior ophthalmic vein (occluded anteriorly) + superior/inferior petrosal sinuses + IJV, (incidental hypoplastic A1)	18
30	Old R depressed skull fracture	-	L CCF , drains to ?R superior ophthalmic vein, no supply from R	-/3
31	Retained knife in L orbit with tip in R posterior temporal fossa	Knife track as per SXR, but passes superior to sella with the tip anterior to the brainstem, Post knife removal: Blood in pontine + R ambient cistern, fracture L medial orbit wall extending into orbital apex + L sphenoid bone, opacified L ethmoid + sphenoid	Normal	Admission
32	-	R proptosis, intraconal air + haematoma, fracture R lateral orbit wall with bone fragment anterior to maxillary antrum, fracture R LWS, ? Irregular R optic nerve, R pneumocephalus + SAH related to sphenoid bone, R track haematoma with intraparenchymal gas locules	Mild spasm R M1, ? Inferior depression of an enlarged R ophthalmic artery	5
33	Occipital + temporal bone fracture	Fracture R lateral orbit wall + temporal bone, R frontal SDH + ICH	-	-
34	Normal	Blood in R ambient wing cistern + R perimesencephalic cistern + R interpeduncular cistern + both occipital horns, R thalamic + R cerebral peduncle haematoma, distended R cavernous sinus, contrast enhancement in L thalamus, ambient cisterns + R cavernous sinus consistent with dilated veins	R CCF, drains to basal vein of Rosenthal + vein of Galen + straight sinus, crossflow present	9 (bad SAH)
35	-	Retained screwdriver through L orbit + petrous bone with tip in midline posterior fossa inferior to torcula	Normal	Admission

36	Normal	IVH, ICH, HC	Not done	-
37	-	R proptosis, pneumocephalus in ambient + suprasellar cisterns, ~ R frontal sinus + medial posterior orbital roof near frontoethmoidal recess	-	-
38	-	Fracture frontal bone, pneumocephalus, knife track	Normal	5
39	Retained knife (14cm) via L orbit with tip to R of midline in upper pontine cistern, ?Glass above R eye	-	Knife compressing L ICA with poor distal flow, no direct vascular injury	Admission
40	Normal	Opacified L maxillary + sphenoid sinuses	L CCF from C3/C4, fills intercavernous and R cavernous sinuses, drains to L superior ophthalmic vein + L inferior petrosal sinus + meningeal veins into superior sagittal sinus, good crossflow	3 (3 months)
41	Normal	Normal	Not done	-
42	-	L orbital gas + proptosis, fracture L GWS, pneumocephalus, L temporal pole ICH, L MCF small SDH	Normal	8
43	Normal	L proptosis, slot fracture L GWS into anterior L temporal fossa, L temporal ICH	Elevated M1 + M2 from temporal pole swelling	9
44	-	R frontal retained blade, L proptosis, R frontoparietal SDH, fracture L frontal sinus into cribriform plate + R superomedial orbit with bone fragments abutting R optic nerve + R inferolateral orbital exit fracture	-	-
45	L lateral orbital rim disrupted, pneumocephalus	L globe disrupted, L SOV thrombosed, pneumocephalus in subarachnoid space + ventricles, fracture superolateral sphenoid sinus @ level of clinoid process + extends into frontal sinus	-	16
46	Pneumocephalus	R frontotemporal haematoma + pneumocephalus, R proptosis, opacified R ethmoid sinus, SDH	Normal	Admission
47	-	-	R CCF, drains to inferior petrosal sinus, good crossflow	- (3 months)
48	Retained knife in orbit	Normal	Normal	Admission
49	Retained knife in medial R orbit, 85mm blade, tip in posterior aspect of sphenoid sinus	Knife extends into medial R temporal lobe	Tip lies 1mm from petrosal segment of R ICA	Admission
50	-	SAH in quadrigeminal + interpeduncular cisterns, pneumocephalus, opacified L sphenoid + ethmoid sinuses, followup CT shows L basal ganglia/thalamic + L parietooccipital infarcts	L CCF, fills intercavernous + R cavernous sinus, drains to R superior ophthalmic vein, both inferior petrosal sinsuses	3
51	-	Pneumocephalus, opacified sphenoid	Normal	5
52	L maxillary + ethmoid opacification, dense R orbit	R proptosis, distended R superior + inferior ophthalmic veins + cavernous sinus, (maxillary sinus not included on scan)	R CCF @ C4 level, drains to R superior + inferior ophthalmic veins + pterygoid plexus + IJV, crossflow present	6 (2 weeks)
53	Retained knife into L frontal sinus, through floor of ACF with tip across midline in R ethmoid sinus, pneumocephalus	Pneumocephalus with intraventricular air, L frontal ICH	Normal	12

Management data.

Case No.	Antibiotics	Anticonvulsants	Endovascular, neurosurgical and ophthalmological management	Duration of hospital stay	Outcome	Follow up
1	No	No	Balloon embolisation	5/10	L CF VA	4 months
2	Amoxycillin	Yes	ACF repair	13	Normal	None
3	Penicillin, Vancomycin, Cloxacillin, Cefuroxime, Metronidazole, Ofloxacin, Cefipime	Yes	ACF repair/isolate frontal sinus	7/60/22	Aphasic, 12/15	To longterm care
4	Cloxacillin, Cefuroxime, Metronidazole	No	FA clipped	17	L 6/12 + ptosis @ 1 week	1 week
5	No	Yes	L evisceration	6	Blind L	6 weeks
6	Cefuroxime, Penicillin, Cefotaxime, Metronidazole	Yes	Bilateral ACF repair	30	Blind L	None
7	No	No	Temporary tarsorrhaphy	13	Blind R	1 month
8	Cefuroxime Cloxacillin	No	None	6	Dead	None
9	Yes	No	R evisceration	19	Blind R	2 months
10	No	No	Balloon embolisation	1/4	Blind R	None
11	Bicillin, Ciprofloxacin	No	L evisceration	6	Blind L	9 months
12	Metronidazole, Cloxacillin, Cefuroxime	Yes	R evisceration	19	R hemiplegia, expressive dysphasia, blind R	6 weeks
13	Penicillin, Gentamycin, Metronidazole, Cloxacillin	Yes	-	10	Well	7 months
14	Yes	No	Craniotomy + knife removal, R enucleation	13	Blind R	2 months
15	-	-	CCF embolisation	6	-	None
16	Ofloxacin, bactrim, Cefuroxime, Metronidazole, Penicillin G, Chloramphenicol, Cloxacillin	Yes	FA clipped, tarsorraphy, external ventricular drain	76	Blind L, poor mental function	5 years
17	-	-	Removal knife	-	-	None
18	No	Yes	Incidental posterior communicating artery aneurysm clipped	30	Blind R, regeneration syndrome, seizures	3 years
19	-	-	Lid repair	0	Well @ discharge	None
20	Cloxacillin, Metronidazole	No	-	6	Well	None
21	Penicillin, Gentamycin, Metronidazole	Yes	None	17	Blind L	3 weeks
22	No	No	Lid repair	7	Well	None
23	-	-	Balloon embolisation	10	Blind L	None
24	No	Yes	Knife removal	6	Well	None

25	No	No	Balloon embolisation	2	Blind R	None
26	-	-	Balloon embolisation	-	-	None
27	Penicillin, Gentamycin, Cloxacillin	Yes	None	19	Blind L, R hemiplegia, dysphasia	16 months
28	No	No	Balloon embolisation	6	-	None
29	No	No	No equipment	9	L poor VA	None
30	No	No	Balloon embolisation, L evisceration	10	Blind L	None
31	Cefuroxime, Ampicillin, Cloxacillin, Metronidazole	Yes	Craniotomy + knife removal, L evisceration	13	Mild L hemiplegia, blind L	9 months
32	No	No	-	5	Blind R	2 weeks
33	Cefuroxime, Metronidazole, Cloxacillin, Cotrimoxazole	Yes	Craniotomy + drainage SDH, R evisceration (for sepsis)	22	Blind R, R hemiplegia	None
34	Gentamycin, Ampicillin	Yes	Balloon embolisation	51	L hemiplegia, wheelchair bound	2 years 3 months
35	No	Yes	Craniotomy + knife removal	31	Mild L hemiplegia, L VII[th] nerve palsy	3 months
36	No	No	Resuscitation	0	Dead	None
37	Penicillin, Metronidazole, Cefuroxime, Cloxacillin	No	None	10	Well	None
38	Cefuroxime	No	None	7	Well	None
39	No	No	Knife removal, L evisceration	10	Blind L	2 months
40	No	No	Balloon embolisation	37	Blind L	None
41	Cefuroxime, Cloxacillin, Penicillin	No	Evisceration, ball implant	10	Blind R	6 weeks
42	No	No	None	9	Blind L, R poor VA	8 months
43	Penicillin, Cefuroxime, Chloramphenicol	No	None	10	L poor VA	None
44	-/Cefuroxime, Cloxacillin, Metronidazole, Amoxycillin	No	Craniotomy + knife removal + drainage SDH, ACF repair	6/23	Blind R	None
45	-	-	-	-	-	None
46	Cefuroxime, Cloxacillin, Amikacin	Yes	Craniotomy + drainage ICH and SDH	18	L hemiplegia, seizures, R poor VA	3 years 6 months
47	No	No	Balloon embolisation	-	Well	None
48	Amoxycillin	No	Knife removal	2	Well	None
49	Penicillin, Metronidazole, Cloxacillin	No	Knife removal	2	Well	None
50	Cefuroxime	No	None	-	Dysphasia	None
51	No	Yes	Corneoscleral repair	7	Well	None
52	No	No	Balloon embolisation	8/9 (no equipment)	Blind R	None
53	Cefuroxime	Yes	Craniotomy + knife removal, ACF repair	24	L poor VA	None