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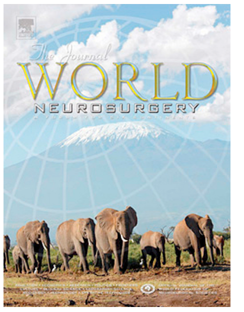

Use of a Minimally Invasive Retractor System for Retrieval of Intracranial Fragments in Wartime Trauma

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ABSTRACT

Objective: Wartime penetrating brain injury can result in deep-seated parenchymal and intraventicular shrapnel, bullets and bone. Large fragments pose a risk of secondary injury from migration, infection and metal toxicity. It has been recommended that aggressive removal of fragments be avoided. The goal of this study is to report our technique of minimally invasive removal of select deep-seated fragments using a tubular retractor system.

Methods**:** A retrospective review of our database of service members presenting with penetrating traumatic brain injuries incurred during Operations Iraqi Freedom and Enduring Freedom, and treated at the Walter Reed Army Medical Center and the National Naval Medical Center, was performed. Six individuals were identified in which the Vycor ViewSite^{TM} retractor system (Vycor Medical, Boca Raton, FL) was used to remove a ventricular or deep intraparenchymal fragment. All patients were male and ranged in age from 21 to 29 years. Fragment location included the foramen of Monro, the atrium of the right lateral ventricle, parasagittally within the right occipital lobe, the occipital horn of the right lateral ventricle, temporally, and within the posterior right temporal lobe deep to the junction of the transverse and sigmoid dural venous sinuses. Fragments included in-driven bone, shrapnel from improvised explosive devices, and bullets.

Results: In all cases the fragment was successfully removed. No patient had worsening of their neurological condition following surgery.

Conclusion: Deep parenchymal and intraventricular fragments can be safely removed using a tubular retractor system.

KEY WORDS

minimally invasive; penetrating brain injury; shrapnel; tubular retractor system; war trauma

INTRODUCTION

Care of patients with penetrating brain injuries and retained intracranial fragments has shifted over the last century. At present, the available data appear indicate that the overall risk of secondary neurologic complications caused by retained material, including potential for infection, migration and toxicity, is relatively low. In some select cases, however, it becomes clear that a retained fragment poses significant risk to a patient, and strong consideration should be given to surgical retrieval. This scenario must be weighed against the possibility for further iatrogenic injury caused by traversing eloquent structures en route to the lesion. In such instances, it is desirable to retrieve the fragment in a manner that causes minimal iatrogenic harm to the patient. Here the authors present a series of six consecutive individuals who sustained penetrating traumatic brain injuries while serving in Operations Iraqi Freedom and Enduring Freedom, that presented with retained intracranial fragments, and who underwent removal of the retained material with a minimally invasive retractor system.

METHODS

The goal of this paper is to describe a novel use for the Vycor ViewSite™ retractor system (Vycor Medical, Boca Raton FL). The authors feel that this technique offers a valid and safe option for treatment of patients that have incurred penetrating bran injuries and that have retained foreign bodies under circumstances in which removal is desirable.

Patients

After IRB approval, a retrospective review of our database of servicemembers presenting with penetrating traumatic brain injuries incurred during Operations Iraqi Freedom and Enduring Freedom and treated at the Walter Reed Army Medical Center and the National Naval Medical Center from March 2004 through December 2012 was performed. Six individuals were identified in which the Vycor ViewSite™ retractor system (Vycor Medical, Boca Raton FL) was used to facilitate removal of an intraventricular or deep intraparenchymal fragment. All patients were male, and ranged in age from 21 to 29 years.

Mechanism of injury was gunshot wound to the head in two individuals, and fragmentation injury to the head from improvised explosive devices in four individuals. Lesion location included the foramen of Monro, the atrium of the right lateral ventricle, parasagittally within the right occipital lobe, the occipital horn of the right lateral ventricle, left temporal lobe, and near the junction of the right transverse and sigmoid dural sinuses. Fragments included shrapnel in three patients, bullets in two patients, and an in-driven bone fragment in one patient.

Vycor ViewSite™ Brain Access System

The Vycor ViewSite™ Brain Access System is a clear plastic tubular retractor system that consists of an introducer fitted within a hollow working channel. The device is available in a variety of lengths (3, 5 and 7 centimeters) and widths (12, 17, 21 and 28 millimeters), allowing the operative plan, choice of approach and working channel to be tailored to each specific patient and each application individually.

Technique

The authors have used the Vycor ViewSite^{TM} in multiple different manners, depending on the depth, location and type of pathology being accessed. In 2011, Recinos *et al* provide an excellent description of their method of using the Vycor ViewSiteTM for resecting deep-seated neoplasms in a series of pediatric patients (27). At our institution, we frequently employ a similar technique. The relative eloquence of the cortical and subcortical structures being traversed, as well as the presence of critical vascular structures in the vicinity of the lesion or on the overlying cortex, are evaluated on pre-operative computed tomography and catheter angiography. The length and width of the retractor is selected based on measurement of the depth and size of the retained fragment on pre-operative computed tomography. The patient is registered using standard stereotactic neuronavigation techniques, and the lesion is localized. An appropriately-sized craniotomy is performed overlying the fragement, and a corticotomy created to accommodate the pre-selected retractor. The authors prefer transcortical as opposed to trans-sulcal approaches. Under image guidance, the retractor can be advance towards the target lesion with stereotactic probe in place. After effectively “docking” on the lesion directly and minimizing disruption to adjacent cerebral tissue, the obturator can be withdrawn, and removal of the retained fragment can proceed. The authors have used this technique effectively at our institution for a wide range of deep-seated lesions, including tumors, in addition to the retained fragments reported in this series.

RESULTS

In all cases, the fragments were successfully removed. All patients tolerated the procedure well, with no new neurologic deficits noted. Post-operatively, all patients underwent computed tomography, and one patient that sustained an isolated penetrating head injury was able to undergo magnetic resonance imaging 13 months from injury; the other five individuals sustained other systemic injuries that precluded the use of MRI. In this individual case, the Vycor ViewSite™ retractor was advanced down the existing tract that was made by the foreign body. In all cases, the post-operative imaging revealed complete removal of targeted fragments, and no untoward complications. A summary of the mechanism of injury, the location of the retained fragments in question, and complications related to their removal, can be seen in in Table 1.

Case Illustration 1

A 29 year old male was injured after stepping on a buried improvised explosive device in January 2012. The patient suffered severe fragmentation injuries to the face, with rupture of the globes bilaterally, and a right-sided extra-axial and intra-parenchymal hematoma requiring surgical evacuation. Multiple bony and metallic fragments, the largest of which measured nearly 1 centimeter in greatest diameter, were driven through the roof of his right orbit and into the right frontal lobe near the frontal horn of the right lateral ventricle. Other injuries included severe bilateral lower extremity injuries necessitating amputation.

The patient's initial CT scan can be seen in Figure 1. Over the course of his hospitalization, the fragments migrated into the right lateral ventricle and descended to the Foramen of Monro. This can be appreciated in Figure 2. Concurrently, the patient developed persistent CSF fistulization from defects in the anterior fossa floor, with evidence of an orbital encephalocoele. He was taken to the operating room a two-part procedure: first, the Vycor ViewSite^{TM} retractor was used to retrieve the intraventricular fragments via a right coronal approach through existing encephalomalacic brain. This portion of the operation was then followed by repair of the anterior fossa floor defects in conjunction with the otolaryngology and plastic surgery services.

Cerebrospinal fluid and tissue cultures taken intraoperatively were positive for *Candida albicans*. He tolerated the procedure well and incurred no new neurological deficits referable to the surgery. The patient completed treatment for the *Candida* meningitis and was transferred to polytrauma rehabilitation in late February 2012. At present the patient legally blind and has a medically-controlled seizure disorder, however cares for himself with minimal assistance from family. A post-operative CT can be seen in Figure 3, demonstrating complete removal of the fragments.

Case Illustration 2

A 24 year old male suffered an isolated penetrating brain injury to the right posterior parietal area after the explosion of an improvised explosive device in July 2011. A single large, round metallic fragment entered approximately 4 centimeters superior to and 2 centimeters anterior to the right asterion, and came to rest immediately adjacent to the occipital horn of the right lateral ventricle. The patient was treated initially with ventriculostomy. The post-ventriculostomy CT can be seen in Figure 4.

Cather angiography, considered standard for penetrating head trauma at our institution, revealed pseudoaneurysm formation in two areas: a right cortical M-4 segment, and along the right calcarine artery. The calcarine artery pseudoaneurysm was amenable to endovascular occlusion; however the M-4 pseudoaneurysm would come to require open microsurgical trapping. At craniotomy, after the pseudoaneurysm was microsurgically obliterated, a Vycor ViewSite™ retractor was next advanced down the existing tract of the fragment under stereotactic guidance, and the metallic foreign body was removed. At last follow-up, the patient exhibited a superior quadrantanopsia referable to the calcarine pseudoaneurysm, and a medically-controlled seizure disorder, but is otherwise independent. The patient's post-operative CT can be seen in Figure 5.

DISCUSSION

The prevailing attitude towards retained intracranial fragments has shifted dramatically since the turn of the twentieth century. The most feared potential complication attributed to retained material has been infection and abscess formation. During World War I, Harvey Cushing was an advocate of meticulous and complete debridement of the wound, with aggressive removal of any foreign material or devitalized tissue (6). Such measures markedly decreased the rates of infection and poor outcome in that population of patients (5, 15, 22, 31). These tenets continued to be applied through World War II, the Korean War and the Vietnam War. The data from these experiences indicated a relatively high rate of meningitis and abscess formation related to retained intracranial foreign material, and standard practice at the time meant many patients often underwent repeat operations to ensure all retained fragments were removed (23). This, however, was not without a resultant increase in complication rate, including worsened neurologic deficit, wound breakdown and cerebrospinal fluid fistula formation.

Standing in contrast to this concept, Pitlyk *et al* in 1970 described a canine experiment in which implanted bone fragments were significantly more likely to lead to suppuration if fur and skin were included, suggesting that it may be in fact the meticulousness of the debridement of the wound entry and exit site, and not retention of fragments *per se*, that led to the increase in complications (25). Indeed, a retrospective review of the data from the Vietnam War by Rish *et al* revealed that less than one-third of patients in which abscesses developed had retained intracranial fragments, and the overall incidence of abscess formation in those with penetrating brain injuries was as low as 3% (28). Along these same lines, Brandvold *et al* found that, among 46 Israeli survivors that had sustained penetrating cranial injuries during the Lebanese conflict of 1982-1985 and were available for follow-up in 1988, 51% had retained material. Further analysis revealed no discernable relationship between the presence of these fragments and rate of infectious complication (4). Aggressive debridement of all foreign material was not pursued in this cohort of patients, and thus the authors concluded that it was unnecessary to place additional potentially functional cerebral tissue at risk by aggressively and completely debriding the wound. A similar conclusion was reached by Amirjamshidi *et al* in a 2003 report of their data from the Iran-Iraq conflict (3). In this study, the authors noted an infection rate of only 5% despite managing the 99 patients within the cohort without surgery or with only minimal local debridement. In 1998, Aarabi *et al* published their results from the Iran-Iraq conflict, and found that, on multivariate analysis, the most important factors that predisposed to infection were CSF fistulization, crossing of paranasal sinuses, and penetration of the cerebral ventricles. Retained fragments were not a risk factor on multivariate analysis (1).

Multiple more recent studies have shown that there is less of a risk than previously suspected when deeply-seated retained fragments are left behind (1, 3, 4). Thus, it seems retained fragments may not pose such a significant risk for infection as once suspected, provided that the entry and exit wounds are meticulously debrided of devitalized tissue. Nonetheless, the risk for serious infectious complications remains in select patients.

Aside from infection, another potential risk to patients with retained fragments is the possibility for migration throughout the neuroaxis. Nearly 100 years ago, in 1916, Vilvandre and Morgan reported the first radiographically confirmed instance of migration of foreign bodies in the brain when they documented the movement of a bullet (18). Since then, multiple studies have found the migration rate to be between 1 and 10 percent, with 4.2% being the rate of migration in the largest series, consisting of 213 patients documented by the Israelis during the Lebanese conflict of 1982-1985 (4). Most cases of migration appear to be clinically insignificant, however there exists in the literature many reports of acute deterioration related to migration, especially when this occurs within the ventricular system (4, 13, 18, 26, 31). In our series, four of the six individuals had retained fragments that were partially or wholly contained within a CSF space, and in one instance a fragment migrated into the ventricular system and settled at the Foramen of Monro (Figure 2), demonstrating the very real possibility of fragment migration.

Metal toxicity that retained metallic fragments may pose is well-documented in the literature, especially when the material is positioned intra-articularly. Synovial fluid appears to act as a solvent in these instances, enhancing the dissolution and absorption of the metal. In the orthopedic literature, extra-articular fragments have traditionally been left in place, although case reports in the literature abound regarding the potential for toxicity in this scenario (7-10, 19, 21). It seems that cerebrospinal fluid can have the same solvent-type effects on retained fragments, potentially leading to toxicity if the projectiles are left in place within the neuroaxis (20). This scenario in the military setting is often complicated by the fact that projectiles may be of an unknown material. Homemade improvised explosive devices can often consist of other metals in addition to lead, including copper, or potentially even radioactive material.

In summary, many authors feel that the risk of pursuing retained fragments outweighs the benefit of removing them, given the relatively low overall likelihood of infection, toxicity and migration. However, in some cases it may be advisable to retrieve such fragments, and in such a situation it is desirable to minimize post-operative deficit related to accessing the lesion. The goal of this paper is to present a novel, minimally invasive technique of accessing these fragments while exposing the patient to minimal morbidity. Current tubular retractor systems provide an excellent means to achieve this goal.

Neurological deficit can result from traversing eloquent cortex and white matter en route to a retained fragment or other lesion. Retraction causes local edema in addition to mechanically disrupting tissues; however some degree of retraction is necessary to access the target lesion (2). Current blade-based retractor systems, including the Greenberg® Brain Retractor, Leyla retractor, and Budde® Halo do not evenly distribute forces along the surgical corridor. Rosenorn and Diemer published a series of papers in which Wistar rats were used to study changes in regional cerebral blood flow and resultant ischemia as graded pressure was applied to the brain, in an effort to simulate the pressure exerted by brain retraction (29, 30). In one study, they applied 20, 30 or 40 mmHg of pressure to the rat's cortex and, using the method of Gjedde, measured the change in regional cerebral blood flow (12). Using this model, they determined that brain undergoing retraction with as little as 20 mmHg pressure was at significant risk for a severe decrease in regional blood flow and resultant ischemia (30). In a follow-up study, the authors expanded on this concept by showing histologically that 20 mm Hg was enough to infarct all cortical layers in one of six subjects, and that 40 mmHg caused a 100% infarction rate of all six cortical layers in the rat model (29).

Since these studies by Rosenorn and Diemer, multiple authors have reported the use of a tubular retractor system that should in theory better distribute the forces of retraction (11, 14, 16, 17, 24, 27, 33). The first use of a tubular retractor was reported by Kelly *et al* in 1987, when a simple metal tube was affixed to a Leksell frame (17). In 2005, Ogura *et al* created a transparent cylinder by rolling a piece of 0.1 mm polyester film and placing it over a thin obturator, and used this device to resect a series of intra-axial hematomas and tumors in 11 patients (24). Of particular importance, the authors used a fiberoptic intraparenchymal pressure monitor in two of these cases to measure the pressure the retractor exerted on surrounding tissue by inserting it next to the rolled film, and found it to be consistently less than 10 mmHg (24).

Recently, the field of neurosurgery has seen the advent of multiple retractor systems specifically tailored for this purpose, including the METRx™ (Medtronic, Minneapolis, MN) spinal retractor system, COMPASS (Compass, Inc., Rochester, MN), and the Vycor ViewSite™ (Vycor Medical, Inc., Boca Raton, FL), among others. Since Ogura *et al* determined the retraction pressure exerted by a tubular retraction system is less than that critical threshold for ischemia delineated by Rosenorn and Diemer, multiple authors have published series of patients operated on successfully using tubular retraction systems (11, 14, 16, 22, 24, 33). Recinos *et al* used postoperative MR imaging to reveal any T2, FLAIR, or DWI/ADC signal abnormality in a series of pediatric patients in whom the Vycor ViewSite™ retractor was used to resect intra-axial neoplasms (27). In 3 of the 4 patients, there was no evidence of white matter damage, and in the individual in which signal change was apparent postoperatively, no new neurologic deficit was noted on examination.

Vycor ViewSite^{TM} retractors are made of lightweight transparent plastic. Unlike metallic retractors, they do not conduct electricity, which may lead to damage to tissues along the surgical corridor, and they allow for observation of surrounding tissue for evidence of hemorrhage, ischemia, or in the context of tumor resection, abnormal-appearing tissue potentially infiltrated by tumor. These features potentially enable safer resection of deep parenchymal and intraventricular lesions.

In select cases in which a retained fragment poses more harm to a patient that does its continued observance, a minimally-invasive tubular retractor system can potentially safely facilitate the foreign body's removal by minimizing injury to the tissue that must be traversed in order to access the fragment.

For the six individuals who underwent surgery, the size and depth of the retained fragment, as well as the rationale for surgery, is summarized in Table 2. The sizes of the retained fragments measured as small as 7 millimeters to as large as 24 millimeters. The largest fragments tended to be retained bullets; their elongated, ellipsoidal shape can be problematic for the working channel is not approached from the correct angle. The depth of the fragments ranged from relatively superficial positions (16 millimeters) to intraventricular fragments encountered at a depth of 53 millimeters from the cortical surface.

The most common rationale for surgery was the fragment resting partially or completely within the ventricular system. This was the case in four of the six patients. In one example, a fragment migrated from a position within the right inferior frontal lobe into the frontal horn of the right lateral ventricle, and down to the Foramen of Monro. These four intraventricular fragments were felt to be pose particular threat based on their position and potential for toxicity and/or migration in such a young population of patients. In one of these patients, the retained foreign body was removed at the time of cranioplasty. In the other patient, the fragment was removed at the time of craniotomy for microsurgical trapping of a traumatic distal middle cerebral artery pseudoaneurysm that had been recalcitrant to therapeutic endovascular measures. In all cases, the target fragments were able to be safely and completely resected. The Vycor was able to provide a safe and effective working channel in all instances, minimizing iatrogenic injury to the patient.

CONCLUSION

With this series of six servicemembers injured in the conflicts in the Middle East, the authors have shown that the Vycor ViewSite^{TM} retractor system can be used to successfully remove deep-seated foreign bodies from injuries sustained in war.

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Age	Mechanism	Fragment	Fragment Location	Days to Removal	Complication
21	IED blast	Shrapnel	Left temporal lobe	81	None
23	IED blast	Shrapnel	Right medial occipital lobe	11	None
24	IED blast	Shrapnel	Occipital horn right lateral ventricle	17	None
24	GSW	Bullet	Atrium right lateral ventricle	12	None
29	IED blast	Bone	Foramen of Monro	20	*Candida* meningitis
29	GSW	Bullet	Right posterior temporal lobe	171	None

Table 1 – Summary of the six patients included in this study.

Age	Mechanism	Fragment	Size (mm)	Depth (mm)	Rationale for Removal
21	IED blast	Shrapnel	16x9	45	Fragment partially within ventricle, removed at time of cranioplasty
23	IED blast	Shrapnel	8x10	27	Large and relatively superficial fragment
24	IED blast	Shrapnel	12x10	30	Fragment partially within ventricle
24	GSW	Bullet	24x6	28	Presence of fragment within ventricle, removed at time of pseudoaneurysm trapping
29	IED blast	Bone	7x7	53	Migration of fragment into ventricle
29	GSW	Bullet	18x7	16	Large and superficial fragment

Table 2 – Characteristics of foreign body and rationale for removal

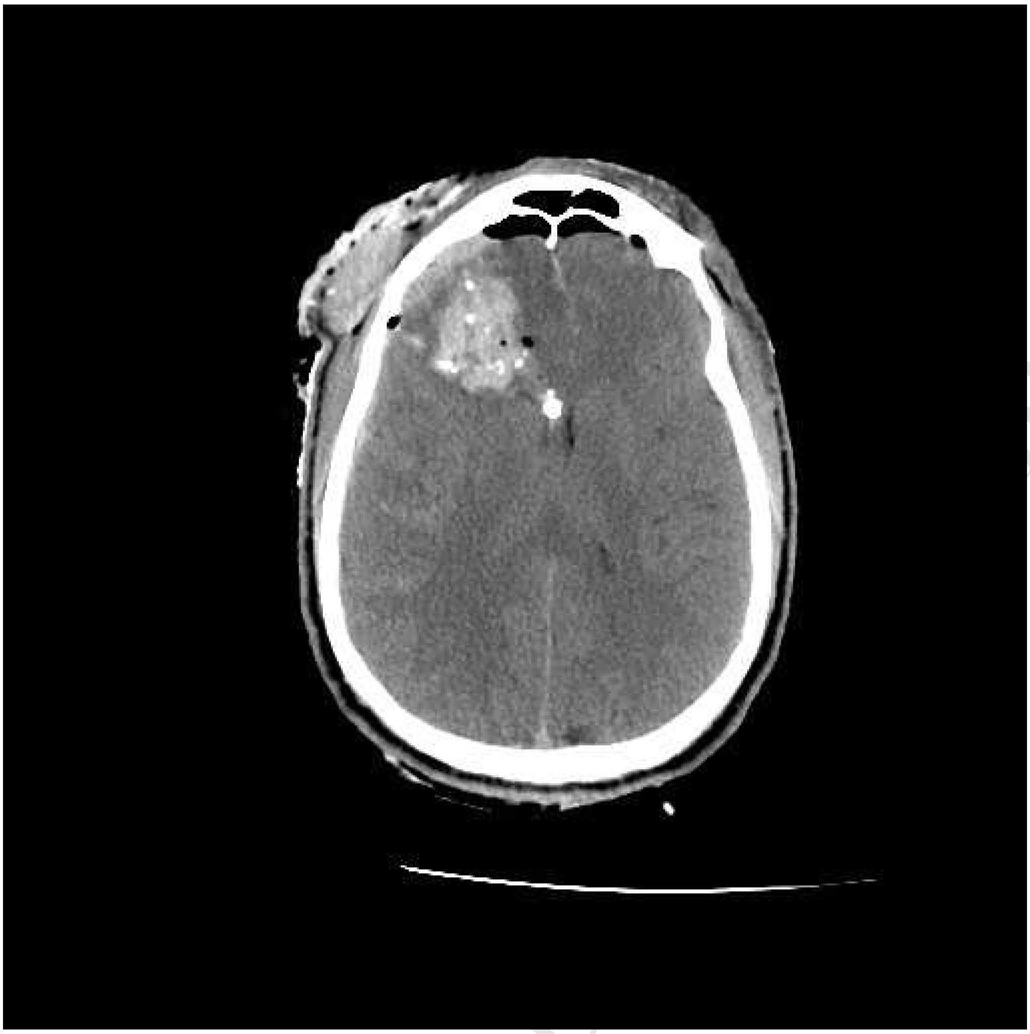
Figure 1 – Initial CT of the patient presented in Case Illustration 1. The fragment can be seen just anteromedial to the angle of the frontal horn of the right lateral ventricle.

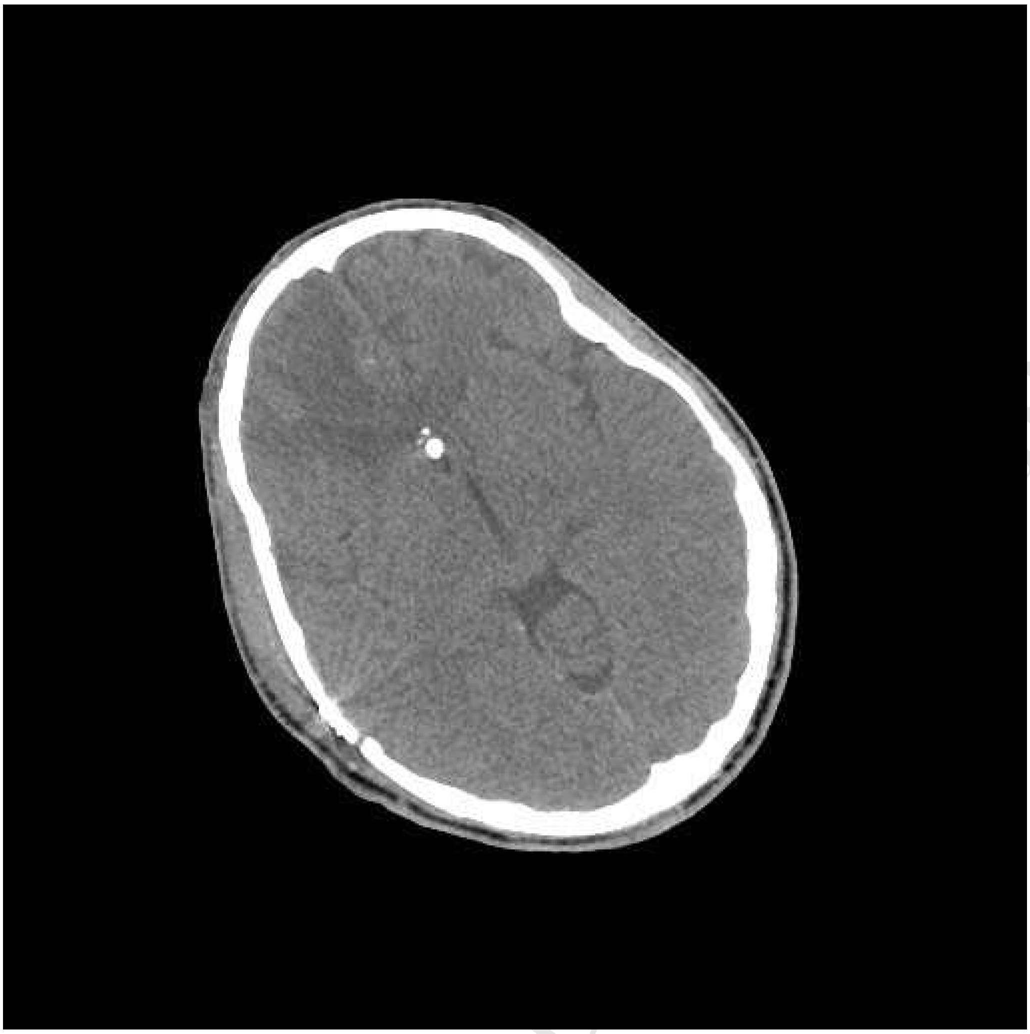
Figure 2 – Serial imaging demonstrates migration of the fragment intraventricularly. It is not resting at the Foramen of Monro.

Figure 3 – Post-operative CT demonstrating successful removal of the fragment.

Figure 4 – CT of the patient presented in Case Illustration 2. A large metallic fragment can be seen immediately adjacent to the atrium/occipital horn of the right lateral ventricle. Right frontal ventriculostomy catheter is seen at the Foramen of Monro.

Figure 5 – Post-operative CT demonstrating successful removal of the fragment.





ADC – apparent diffusion coefficient

CT – computed tomography

DWI – diffusion weighted imaging

FLAIR – fluid attenuated inversion recovery

IRB – institutional review board

mm Hg – millimeter of mercury

MRI – magnetic resonance imaging

T2 – T2-weighted magnetic resonance imaging

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DISCLAIMER

The views expressed in the following text are those of the authors and do not necessarily reflect The official policy or position of the Department of the Army, Department of the Navy, Department of Defense, nor the U.S. Government.

CONFLICT OF INTEREST

The authors report no conflict of interest in preparation of this manuscript.