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Traumatic CSF leaks of the anterior skull base

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Abstract. *Traumatic CSF leaks of the anterior skull base*. Skull base fractures are a frequent complication of high-impact trauma; due to the inherent anatomic relationships of the skull base, they may be associated with significant intracranial complications, including CSF leakage, and their detection is therefore important. The ethmoid roof and the cribriform plate region are the sites most vulnerable to fractures and dural tears. Rhinorrhoea is a non-specific finding; the presence of CSF in a sample must be confirmed with beta 2 transferin or beta trace protein. Accurate identification of the leakage site is necessary for a successful surgical treatment. Various modalities are available for this purpose, such as CT scan and MRI.

Persistent CSF rhinorrhoea necessitates surgical intervention, due to the risk of meningitis. Continued improvements in endoscopic reconstruction techniques have led to fewer open surgeries for repair. Smaller defects can be closed with fat, gasket technique or free grafts, while larger defects necessitate a multilayer closure with local vascularized flaps. These techniques have shown consistently high success rates.

Introduction

Four per cent of all head injuries include skull base fractures; most of these fractures (90%) are secondary to closed head trauma, with the remainder due to penetrating injury. Fractures that extend through the floor of the anterior, middle, or posterior cranial fossa are mostly caused by relatively high-velocity trauma, most often high-speed motor vehicle accidents, although motorcycle collisions, pedestrian injuries, falls, and assault are additional associated causes. Penetrating traumas, particularly gunshot wounds, are seen much less frequently, and account for fewer than 10% of cases.[1]

Despite the clinical importance of skull base fractures, many are undiagnosed, since they are often seen within the context of complex facial or orbital fractures. The detection of basilar skull fractures is important, since even linear non-displaced fractures may be associated with numerous critical complications. Due to the complex anatomy of the skull base and the close presence of blood vessels and nerves, fractures are often accompanied by damage to the neighbouring structures, including the cranial nerves, the internal carotid artery, and the cavernous sinus.

Fractures may lacerate the dura and create a potential cerebrospinal fluid (CSF) fistula. CSF leaks occur in 12% to 20% of patients with skull base fractures. Traumatic leaks usually begin within 48 hours, and 95% of these manifest within three months of injury. In the majority of these patients, the leak stops spontaneously within a few weeks, and over 70% of these leaks close with observation or with conservative treatment such as bed rest or lumbar drainage. Leaks that close without surgical repair are likely to be covered by only a thin monolayer of fibrous tissue or regenerated nasal mucosa, because the dura mater does not regenerate (8). Although conservative treatment may be effective in leak cessation, it has been associated with a significant incidence of ascending meningitis. Meningitis and/or encephalitis occur in 20% to 30% of patients with a CSF leak.[1,2] When a fracture of the skull base is suspected, insertion of a nasogastric tube should be avoided; the orogastric

Table 1

Locations of anterior skull base fractures[3]

Location	%
Frontal sinus	95
Orbital plate of frontal bone	65
Lamina cribrosa	63
Sphenoid sinus	49
Temporal bone	30
Sphenoid wing	28
Carotid Canal	26

Table 2

Clinical findings associated with anterior skull base fractures [3]

Finding	%
Periorbital oedema	49
Periorbital ecchymosis	44
Epistaxis	40
Sluggish or nonreactive pupils	28
Haemotympanum	19
Ophthalmoplegia	7
CNVII palsy	7
Meningitis	7
Otorrhoea	5
Visible brain matter	5
Seizure	5
Proptosis	5
Rhinorrhoea	2
Decorticate posturing	2

route is preferred, as there have been cases of intracranial nasogastric tube placement in the presence of cribriform plate fractures.

Skull base vascular injuries occur in about 50% of patients with skull base fractures. Most of these injuries are "silent" and have no clinical impact. However, vascular injury may lead to a devastating neurological outcome and death. [3]

Anatomy

The skull base is made up of seven bones: the paired frontal and temporal bones, and the unpaired ethmoid, sphenoid, and occipital bones. It is divided into anterior, central, and posterior regions, which form the floor of the anterior, middle, and posterior cranial fossae. The skull base is uniquely positioned to absorb force imparted to the craniofacial skeleton, thereby reducing brain injury.[4] The anterior skull base as a structure is not uniform; its thickness varies significantly. Centrally, it has a delicate lattice-like structure, whereas laterally, its bony architecture is more robust.

It has long been accepted that the skeleton of the midface, by virtue of the presence of the nasal cavity, paranasal sinuses, and orbits, acts as an 'air-bag' or 'crumple zone' protecting both the contents of the orbit and the intracranial contents by dissipating forces before they reach these structures.

The ethmoid roof and the cribriform plate region are the sites most vulnerable to dural tears (Table I). The junction between the cribriform plate and the ethmoidal labyrinth is particularly susceptible to traumatic injury, since the bone in this structure is delicate, and the adjacent dura is tightly adherent. Hence, patients with anterior skull base fractures are at high risk of developing CSF fistulae.[1]

Clinical findings and symptoms of skull base fractures

Depending on the localization and severity of the trauma, the clinical findings and symptoms may vary from periorbital oedema to severe intracranial complications (Table 2). Rhinorrhoea is a common complaint in any rhinology practice, but the significance of this symptom is entirely different when it is a manifestation of a CSF leak. CSF rhinorrhoea is the result of an abnormal communication between the subarachnoid space and the sinonasal tract.[3] Flow of CSF rhinorrhoea may be a constant dripping or may be intermittent, depending on the patient's position. For trauma patients, CSF rhinorrhoea develops within 48 hours in approximately 55% of all patients who ultimately develop CSF rhinorrhoea as a result of trauma. This frequency increases to 70% by the end of the first week, as oedema, which may be temporarily preventing CSF leakage, resolves.[5]

Detection of CSF rhinorrhoea

Although rhinorrhoea is a non-specific finding, the presence of CSF in a sample must be confirmed before invasive testing is pursued. The accurate diagnosis of a CSF fistula depends on the demonstration of extracranial CSF. There are several ways to identify whether the fluid from the nose is CSF.

The ring sign

CSF combined with blood can leave a "ring" or a "halo" on bed sheets or similar white media.[6] A target-like double ring will appear, since CSF is less dense and migrates farther from the centre than blood.[7] This "ring sign" has been discussed as the first indicator of a CSF leak, especially in a trauma patient; however, the reliability of this sign is poor.[8]

Glucose detection

Testing clear rhinorrhoea for glucose was traditionally considered to be an option for a rapid diagnosis of CSF leak, in the belief that only the presence of CSF would lead to a positive glucose result. However, this assumption has been challenged over the last few decades. Although glucose is not detected in normal human airway secretions, it is detectable in settings of acute airway inflammation or hyperglycaemia, both of which are commonly found in acute skull-base trauma patients.[8] Chan found that the test strips are non-specific (0% specificity) and poorly sensitive (80%) compared to beta-2 transferrin, which was considered the gold standard in this study.[7] Overall, glucose detection is not recommended as a confirmatory test, due to its lack of specificity and sensitivity.

Beta 2 transferrin

Beta-2 transferrin is a glycoprotein that is present in CSF, but is not detected in nasal secretions or surrounding tissue, thus allowing it to be used as a marker for CSF leak. Approximately 2–5 ml are required in order to achieve good sensitivity and to compensate for low CSF transferrin concentration. Consistently high sensitivities and specificities have been reported in multiple studies; Warnecke reported a beta-2 transferrin sensitivity and specificity of 97% and 99%, with positive and negative predictive values of 97% and 99%.[9] It is a non-invasive and inexpensive detection method, and is therefore recommended as the primary screening method for possible CSF rhinorrhoea.

Beta trace protein

Similarly to beta-2 transferrin, beta trace protein is also present in high concentrations in the CSF, and is produced primarily in the leptomeninges and choroid plexus. Results are typically available within 20 min and tests require relatively small (200 µl) sample volumes. The sensitivity and specificity of beta trace protein testing ranges from 91%–100% and 86%–100%, rivalling beta-2 transferrin in terms of accuracy.[10-12] Renal insufficiency and bacterial meningitis greatly increase and decrease CSF levels of beta trace protein respectively, and the test should therefore not be used in these population groups. This screening method merits consideration, since it can offer potential benefits such as even lower cost and faster results, with a comparable accuracy to that of beta-2 transferrin.[12]

Radionuclide cisternography (RNC)

RNC is a nuclear medicine test in which a radioisotope is injected intrathecally via lumbar puncture, and pledgets are then placed in the nasal cavities for several hours at a time, before being removed and measured for radioactive tracer. This study may be more effective in detecting a CSF leak that is too slow or intermittent to produce a sufficient sample for beta-2 transferrin or beta trace protein testing. It is a diagnostic or confirmatory study rather than a localization study; it cannot guarantee that the CSF is from a rhinologic leak rather than an otologic leak that has travelled down the Eustachian tube into the nasopharynx. Although the level of evidence is rather low, the available data indicate that this is a more invasive, more expensive, and less accurate test than beta-2 transferrin or beta trace protein. Based on these facts, RNC should not be routinely employed to confirm the presence of a CSF leak.[13-16]

Localization of the CSF leak

Accurate identification of the leakage site is necessary for a successful surgical treatment. Various modalities are available for this purpose including high resolution CT (HRCT), magnetic resonance cisternography (MRC) and intrathecal fluorescein (IF). Although HRCT is primarily a localization tool, the others are capable of simultaneous confirmation and localization.

High resolution CT (HRCT)

High resolution CT scans of the entire craniofacial region can be obtained in seconds to minutes. This technique provides a reasonably accurate assessment of the bony structures of the craniofacial skeleton. Coronal and axial studies are mandatory for evaluation of the skull base. Axial scanning is useful for detecting fractures in vertical structures, such as the medial and lateral orbital walls and vertical sinus walls; the coronal scan best demonstrates horizontal structures, such as the floor and roof of the orbit and vertical sinus walls. Although CT scanning can localize a fracture line or intracranial air, it fails to indicate persistent violation of the leptomeninges with CSF leakage, and may miss some fractures. In the context of a CSF leak localization, HRCT has a sensitivity and specificity of 44%–100% and 45%–100% respectively. Positive predictive and negative predictive values have been reported as 100% and 50%–70%, with an accuracy of 87%–93%.[7] HRCT appears to be the best initial choice for localization, and is one that will be obtained in most cases simply to provide the surgeon with knowledge of the anatomy.

Magnetic resonance cisternography

MRC is a common imaging modality used for CSF leak diagnosis. It is a non-invasive study, capable of both leak confirmation and site localization by the inherent bright signal of CSF on T2-weighted images passing from intracranial into paranasal sinuses, as well as by the identification of herniated soft tissue in skull-base defects.[8] The main disadvantages of MRI are high cost and limited access. A related imaging technique that is also described in many of these studies is intrathecal gadolinium-enhanced MRC (CE-MRC). Although this study foregoes the non-invasive benefits of standard MRC, many feel it is a safe and effective alternative for identifying CSF fistula.

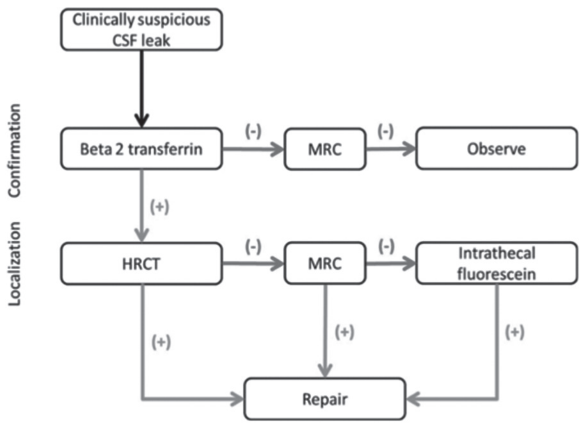

Figure 1
Diagnostic algorithm for suspected CSF leaks [3]

Intrathecal and local fluorescein

Intrathecal fluorescein is a common method for preoperative localization of the fistula. Fluorescein is injected into the subarachnoid space through a lumbar puncture.[17-19] As described above, many modalities exist for the confirmation and localization of a skull-base CSF leak. These modalities vary greatly in their benefits, costs, and risks. A proposed algorithm for the optimal pathway for diagnosing CSF leaks is shown in Figure 1.

Surgical treatment

Indications for surgical treatment

Persistent CSF rhinorrhoea necessitates surgical intervention because of the risk of meningitis, which has been reported to range from 10% to 37% during conservative management.[20, 21] Surgery is reserved for the treatment of CSF leaks that do not spontaneously close or respond to conservative management with CSF diversion.[22] Early surgical intervention is recommended in cases where the intracranial pathology requires acute intervention or the anatomy of the skull fracture suggests that spontaneous closure would be impossible, such as in a large depressed skull base fracture, a fracture accompanied by complications (for example, cranial nerve deficits), or tension pneumocephalus. The main goal of treatment is reconstitution of the cranial base anatomy to stop CSF leakage and prevent meningitis and mucocoele formation, while optimizing the cosmetic outcome.[3] Major challenges of anterior skull base repair include not only reconstruction of the defect but also decision making about the extent of the surgical approach (endoscopic, open, or a combination thereof) and the appropriate reconstruction strategy (choice of vascularized flap).[3] Two types of approaches for the repair of a post-traumatic dural defect and a consequent CSF leak have been described in the literature: the transcranial approach and the extracranial endoscopic approach. Transcranial approaches were first described by Dandy in 1926, as he reported the first successful dural defect repair. Extracranial approaches have improved over recent years with advancements in endoscopic sinus surgery. Endoscopic repair of the anterior skull base defects avoids the morbidity of open approaches, and in particular for brain retraction, anosmia and craniotomy.[23] A variety of endoscopic repair techniques are now well described. Critical factors that affect the outcome of the reconstruction are location, arachnoid disruption, size and raised intracranial pressure.

Small defects and free tissue grafts (defect size small <1 cm)

Small defects generally do not need a repair with a vascularized flap. Several reconstruction techniques and materials have been described ranging from autologous tissues of various origins (fat, fascia lata, and fascia temporalis) to non-autologous tissues (lyophilized dura, cadaver dermis or cadaver fascia lata. Overall, these techniques work well for small skull base defects with size < 1cm.

The bath plug technique (Figure 2) is a closure of a small CSF leak with autologous fat. The technique consists of introducing a fat plug with a specifically secured vicryl suture into the intradural space and placing traction on the suture to seal the defect, much as a bath plug seals a bath.[24]

Free mucosal grafts such as the inferior turbinate can provide a graft of reasonable size with minor donor site morbidity. The mucosa surrounding the leak site is elevated and removed to create a wide exposure. Removal of the mucosa is an important step in order to break the fistulous tract, freshen the edges of the leak site and allow epithelium and scar tissue to heal over the leak site. The bony edges of the defect can also be drilled or curetted to stimulate osteoneogenesis. Once the leak site is prepared, placement of grafts can be performed.

A third technique for closing smaller defects is the gasket seal closure. For the gasket seal to be effective, the defect in the skull base must be surrounded by a rim of bone. Fascia lata grafts are harvested from the thigh. The fascia lata graft is fashioned with the same dimensions as the cranial base defect but with an additional 2 cm of diameter, so as to extend 1 cm beyond the edge of the cranial base defect circumferentially. The fascia lata graft is placed over the defect. A piece of vomer or cartilage is cut to the same size as the defect. This rigid buttress is placed over the fascia lata graft and countersunk into the defect so that the edges of the buttress are wedged just beyond the bony edges of the defect, holding it in place. The centre of the fascia lata graft is intracranial, whereas the edges remain in the sinus cavity, similar to a cauliflower leaf (Figure 3). The fascia lata, which is circumferentially wedged between the bony edge of the cranial defect and the graft, creates a watertight gasket seal.[25]

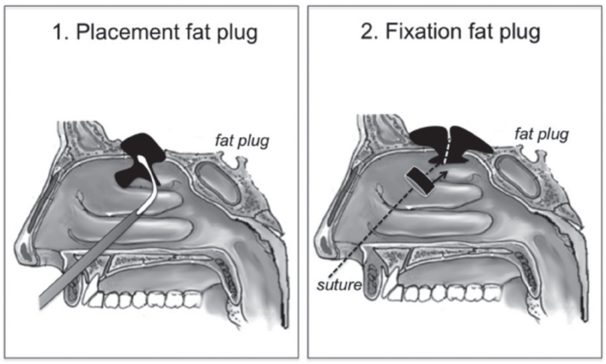

Figure 2
Bath plug technique

Larger defects

Positioning of the grafts

The grafts can be placed in an “underlay” (in the epidural space), an “inlay” (in the subdural space) or an “onlay” or “overlay” manner (in the extracranial, intranasal space). The epidural underlay graft is placed between the bone and the dura mater, while the intradural inlay graft is placed in the subdural space (Figure 4). Inlay or underlay grafting requires remaining bony edges under which the graft can be safely tucked. In the absence of bony edges, especially in the proximity of neurovascular structures such as defects of the planum sphenoidale or the lateral sphenoid wall adjacent to the internal carotid artery or optic nerve, this inlay grafting can be difficult. As a consequence, an inlay graft is not always possible.

The inlay technique is technically more demanding than the overlay technique. Inlay grafting is also suited to the repair of defects of the posterior wall of the frontal sinus, the cribriform plate, the ethmoid roof, and the sphenoid sinus in some cases. The onlay (overlay) technique is recommended if there is a risk of injury to nerves or vessels.

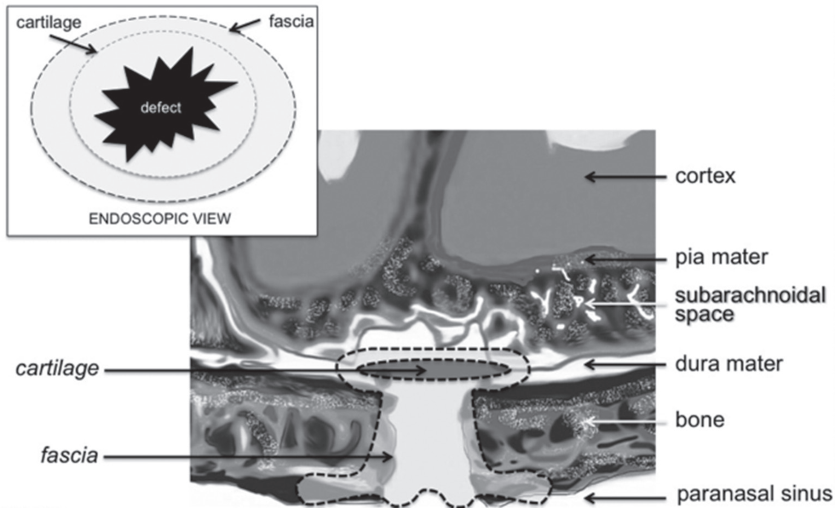

Figure 3
Gasket technique

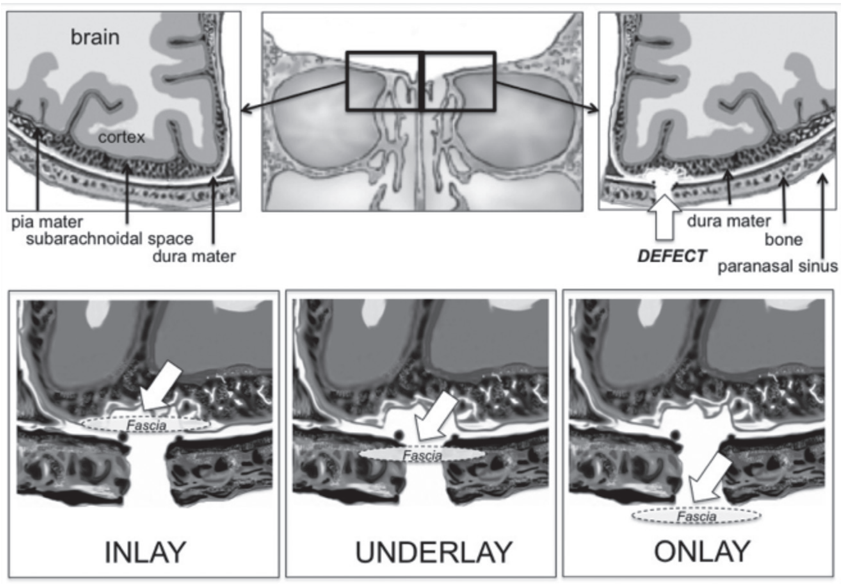

Figure 4
Graft positioning

Multi-layer technique

Larger defects have traditionally been repaired using regional vascularized flaps in a multi-layer closure. A first layer consists of fat, the second is an inlay graft with fascial lata and the next consists of an onlay graft, placed extracranially between the skull base and the sinonasal tract (Figure 5). The underlying mucosa should be completely removed from the bone, to allow direct contact for vascularization of the onlay graft.[26] This onlay graft can be fascia lata or a local pedicled flap. Local pedicled flaps provide a very robust and reliable method for closure. The nasoseptal Hadad-Bassagaisteguy flap is currently the gold standard for the closure of skull base defects after endoscopic transnasal surgery. This flap is both reliable and robust due to the robust vascular pedicle. The nasoseptal flap is pedicled on the nasoseptal artery which forms the posterior branch of the sphenopalatine artery, which in turn is one of the terminal branches of the internal maxillary artery. The generous dimensions

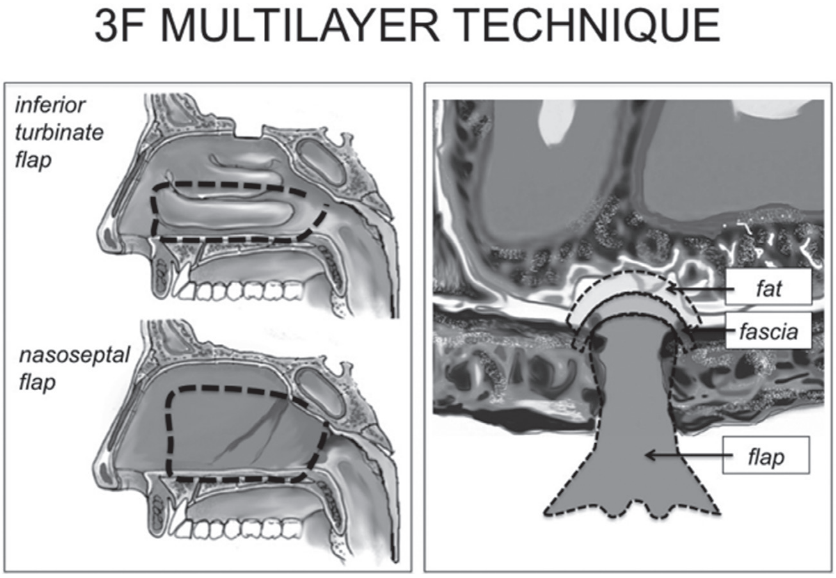

Figure 5
Multilayer reconstruction

and the versatility of the flap enable the coverage of large defects between the anterior skull base at the frontal sinus and the craniocervical junction, and from orbit to orbit. Careful elevation of this flap yields about 25 cm^2 of vascularized tissue.[27] The final layer is the fibrin sealant that is applied to help stabilize and seal the margins of the graft. To mitigate the effects of graft migration and the development of persistent channels, a balloon stent can be used to apply pressure.

Intracranial approach

Although otorhinolaryngologists are now able to successfully access all areas of the anterior and central skull base, there are still limitations to extracranial approaches, and certain cases are more amenable to neurosurgical repair by way of craniotomy. These may include patients with multiple, comminuted defects, broadly attenuated or badly deformed skull bases, tumours with intracranial extension, large bilateral defects in an anosmic patient, and high-pressure leaks requiring CSF diversion procedures.[2]

Success rate

The success rate of endoscopic CSF repair ranges from 87%–100% after the first attempt, and from 94%–100% after the second attempt.[28-30] The precise locations of leakage prior to surgery, and proper patient selection by eliminating cases with large defects, are helpful in ensuring a successful endoscopic CSF repair. One should be careful in determining success in CSF rhinorrhoea, as recurrences may occur very late. The mean interval until failure was 80 months in the series by Gassner et al.[31] This highlights the need for long follow-up.

Additional therapies

1. Lumbar drainage
Sixty-seven per cent of otolaryngologists surveyed routinely use lumbar drains as part of their management of CSF fistulae.[17] Although commonly cited indications include large defects, coexistent meningoencephaloceles and associated high intracranial pressure, their routine use remains controversial, with several series reporting high rates of closure even in cases with large skull base defects.[20,21] Unfortunately, the benefit of lumbar drains in CSF leak repair could not be ascertained by the data provided by the studies included in this systematic review.[1,32]

Abbreviations

CSF : cerebrospinal fluid
CT : computed tomography

HRCT : high-resolution CT scan
IF : intrathecal fluorescein
MRC : magnetic resonance cisternography
MRI : magnetic resonance imaging
RNC : radionuclide cisternography

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