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Review

State of the art of endoscopic frontal sinus cerebrospinal fluid leak repair

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ABSTRACT

Frontal sinus cerebrospinal fluid leaks are rare and their surgical management is difficult. Up until recently, they could only be treated by open surgery with an osteoplastic flap. With the development of endoscopic surgery, less invasive techniques such as an exclusive endoscopic approach can now be used, ensuring a simpler postoperative course. However, these techniques require a thorough knowledge of frontal sinus anatomy and endoscopic CSF leak repair. This knowledge is essential both to ensure closure of the CSF leak and to preserve frontal sinus patency.

1. Introduction

Frontal sinus cerebrospinal fluid (CSF) leaks are rare and difficult to treat. These CSF leaks can be variably associated with meningocele or meningoencephalocele, which further complicates their management, especially in the presence of large meningeal herniation. CSF leaks are due to various causes: they can follow high-energy trauma (road accident) or surgical trauma (iatrogenic). They can be secondary to a tumour of the nasal cavities, or may be congenital [1]. Congenital CSF leaks are observed during childhood and are frequently associated with meningoencephalocele. Finally, they can be spontaneous, in which case the presence of a specific and frequently underestimated entity, benign intracranial hypertension (BIH) must be investigated. This entity, also called pseudotumor cerebri, is classically observed in middle-aged (4^{th} decade), overweight or obese women [2,3]. It is accompanied by signs of intracranial hypertension: headache, nausea, pulsatile tinnitus, papilloedema, etc. MRI frequently demonstrates normal or small ventricles associated with an empty sella turcica or enlargement of the optic nerve sheath [4].

The diagnosis of CSF leak requires demonstration of CSF in nasal secretions, either directly by collection of CSF rhinorrhoea, or by examination of nasal packs left in place for 24 hours. The positive diagnosis is preferably established by immunonephelometric assay of beta-trace protein in secretions or electrophoretic demonstration of beta2-transferrin [5–7]. Imaging assessment by computed tomography (CT) and magnetic resonance imaging (MRI) is essential to formally identify and localize the CSF leak [7].

Historically, the treatment of frontal sinus CSF leaks required open surgery with creation of a frontal sinus bone flap [8,9]. Since the development of endoscopic surgery, less invasive techniques such as exclusive endoscopic approaches are now available, allowing a simpler postoperative course [10]. The objective of this article is to describe the indications, technique and type of operation allowing frontal sinus CSF leak repair.

2. Indications and patient selection

The preoperative work-up consists of a thorough clinical interview, nasal endoscopy and radiological assessment.

The history of the present illness must establish the cause of the CSF leak/meningocele: traumatic, congenital, neoplastic or spontaneous. In the case of spontaneous CSF leak, BIH must be eliminated.

2.1. Endoscopic examination

Endoscopic examination can sometimes confirm and localize a large meningocele, which presents as a pulsatile, translucent submucosal mass. A CSF leak is only very rarely visible on endoscopy. Nasal endoscopy must therefore identify any local anatomical variants that may interfere with surgery: deviated septum or septal spine, synechiae, etc.

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2.2. Imaging assessment

High resolution CT and MRI of the sinuses are essential for the diagnosis and localization of the CSF leak/meningocele [6]. CT of the sinuses with sagittal sections every 3 mm is particularly useful to identify defects over the frontal recess and to study its anatomy.

According to Schlosser et al., CSF leaks can be classified into three main sites (Fig. 1) [11]:

- type 1: immediately adjacent to the frontal recess;
- type 2: in the frontal recess;
- type 3: in the frontal sinus itself.

Type 1 CSF rhinorrhoea concerns leaks arising from the most anterior part of the ethmoidal roof or the cribriform plate. It does not directly involve the frontal sinus, but requires complete dissection of the frontal recess to allow exposure and optimal repair of the leak and to ensure long-term frontal sinus patency.

Type 2 CSF rhinorrhoea is more difficult to treat because it directly involves drainage of the frontal sinus. The difficulty of treating CSF leaks in this region depends directly on local anatomy, which is highly variable in the region of the frontal recess [12]. When maintenance of frontal sinus patency appears to be difficult, open surgery should be considered [9].

Type 3 CSF rhinorrhoea concerns leaks of the posterior wall of the frontal sinus situated above the frontal recess. Prior to the recent progress in endoscopic frontal sinus surgery, these CSF leaks were systematically treated by open surgery. The limits of endoscopic surgery currently correspond to the most lateral and most superior CSF leaks (Fig. 2).

Shi et al. proposed another classification, based on the site and size of the CSF leak, allowing the surgeon to select the most appropriate approach [13].

Type A CSF rhinorrhoea concerns leaks of the posterior wall of the frontal sinus situated at the level of the frontal recess and less than 1 cm in diameter. These CSF leaks can be treated by a classical endoscopic approach after clearance of the agger nasi and frontal recess.

In type B, the CSF leak is situated on the posterior wall of the frontal sinus. Exposure and adequate visualization of the defect require frontal sinusotomy. In type C, the defect is generally larger than 1 cm in diameter with a small frontal sinus ostium (anteroposterior dimension < 6 mm), a poorly pneumatized agger nasi or a defect localized on the posterolateral wall of the frontal sinus. According to Shi et al., type C leaks constitute an indication for a combined endoscopic and open approach [13].

The most lateral and most superior defects of the posterior wall of the frontal sinus are currently considered to be unsuitable for endoscopic repair, and require open surgery [10,11]. On the contrary, CSF leaks situated immediately in contact with or inside the frontal recess appear to constitute good indications for exclusive endoscopic treatment [10,13,14]. In this case, clearance of the frontal recess can be sufficient to provide access to the defect. The higher the CSF leak on the posterior wall the more difficult the frontal sinus is to treat endoscopically: anatomical studies have shown that conventional endonasal instruments are unable to reach the superior limits of the frontal sinus. However, a CSF leak in this zone can be easily visualized [15]. The convex shape of the posterior wall of the frontal sinus probably accounts for this limited access [15,16]. In a series of 37 consecutive patients treated endoscopically, Jones et al. studied the distance between the superior pole of the CSF leak and the most anterior and most medial part of the roof of the ethmoid sinus, just anterior to the frontal recess: the highest defect that could be successfully treated was situated at a distance of 30 mm, with a mean distance for the series of only 6.9 mm [10]. Sieskiewicz et al. proposed drawing a line on preoperative sagittal CT sections between the most anteroinferior point of the frontal sinus ostium to the inferior part of the defect on the posterior wall of the frontal sinus in order to evaluate the feasibility of exclusive endoscopic repair. If the line reaches the defect without touching the posterior wall of the frontal sinus, the instrumentation required to fill the CSF leak can be adequately placed with, if necessary, slight compression of the dura mater [16]. In contrast, if the line crosses or remains tangential to the posterior wall of the frontal sinus, endoscopic CSF leak repair will be impossible (Fig. 3). Although rarely reported, endoscopic repair of lateral CSF leaks appears to be possible, but requires extensive enlargement of the frontal sinus ostium [17]. After performing Draf type III frontal sinusotomy, the most lateral margin of the frontal sinus can still be visualized, but endoscopic instruments are able to reach the defect in only 64% of cases (Fig. 4) [15,18].

Factors other than the site of the CSF leak must also be taken into account to ensure successful endoscopic repair: the size of the defect, the presence of anatomical variants of the frontal sinus, the surgeon's experience and the availability of specific instruments.

Size is not the most important factor when deciding whether or not to use an endoscopic approach, but raises the problem of the type of reconstruction and the material that should be used. A large defect (e.g. a large encephalocele or following tumour resection) will require more elaborate repair techniques and a minimum of surgical skills in a narrow operative field. These factors must be taken into account when deciding whether or not to perform exclusive endoscopic repair. The repair of large defects measuring up to 48×35 mm after tumour resection by Draf type III frontal sinusotomy and nasoseptal flaps has been reported [10].

Among the various possible anatomical variants, a narrow frontal sinus ostium is not a contraindication to an endoscopic procedure, as it can be easily enlarged by an experienced surgeon by means of Draf frontal sinusotomy [9]. A very convex posterior wall can limit access to the superior and/or lateral part of the sinus. A narrow frontal sinus with an anteroposterior distance less than 1 cm is considered to be an unfavourable anatomical condition for endoscopic surgery [16].

The frontal sinus is one of the most technically demanding zones of endoscopic sinus surgery. The keys to success of frontal sinus CSF leak repair are a good knowledge of both the frontal sinus anatomy and CSF leak repair techniques. The surgeon must be familiar with the anatomy of the frontal sinus and its variants and must be able to perform several types of frontal sinusotomies if necessary (Draf I to III). Neurorhinologists, familiar with 3- or 4-hand techniques as well as the complete range of skull base repair techniques, are particularly skilled in this type of operation [19].

Surgical navigation must be used when available [10,20]. A high definition video tower, 45° and 70° endoscopes, 70° angulated drills and malleable frontal sinus curettes, Kuhn 55° and 90° frontal sinus curettes and curved suction cannulae are essential instruments to access and operate on the frontal sinus.

3. Endoscopic surgical technique

Surgery is performed under general anaesthesia with the patient placed in the supine position. It can be performed by one surgeon or by two surgeons using 3- or 4-hand techniques. The operative field must include zones that will be used to harvest autologous tissue used to repair the CSF leak (e.g. abdominal fat or fascia lata). Lumbar drainage may be used when BIH is suspected or after failure of previous surgery [21]. Lumbar drainage may facilitate the use of intrathecal fluorescein, recommended by many authors to precisely localize the zone of CSF leakage and to confirm successful leak repair [10,22–24]. However, this use of fluorescein is off-label in France and in many other countries, including the USA, where it

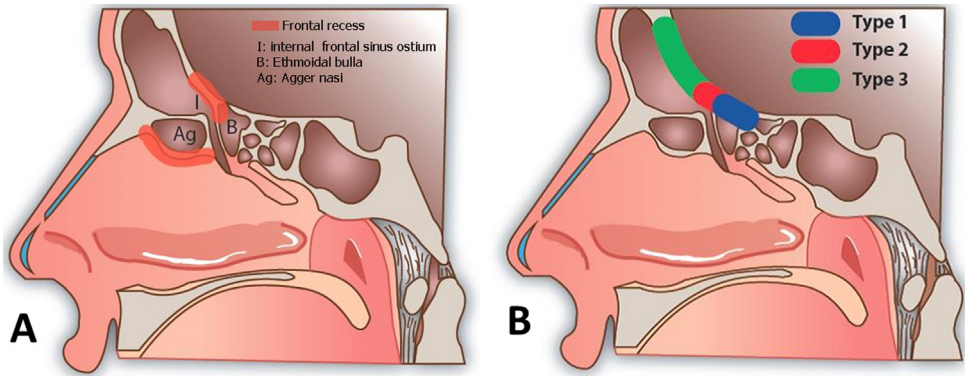

Fig. 1. A. Anatomy of the frontal recess. B. Classification according to Schlosser et al.

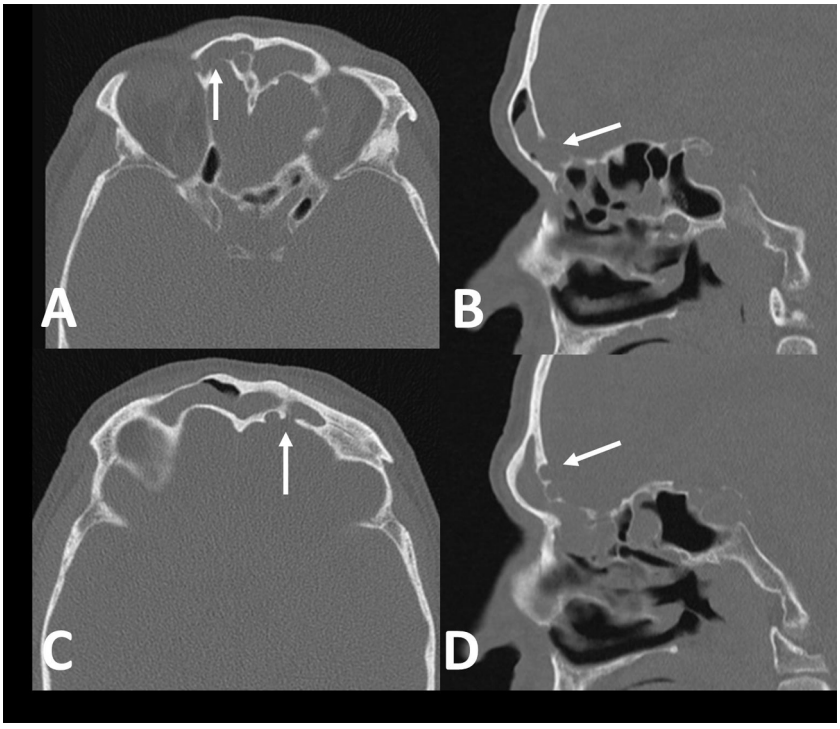

Fig. 2. Bilateral Schlosser type 3 post-traumatic CSF leaks. CT scan, axial (A) and sagittal (B) views of the right CSF leak. CT scan, axial (C) and sagittal (D) views of the left CSF leak. This patient was operated by a combined approach. A Draf 3 type frontal sinusotomy allowed repair of the leak with TachoSil (Baxter, Deerfield, USA), septal cartilage and a septal mucosa flap. On the left, a supraciliary incision was necessary due to the very high and lateral site of the CSF leak. The patient remained asymptomatic 1 year after surgery.

is commonly used. After preparation with xylocaine-naphazoline, the nasal cavities are carefully inspected. A perfectly clear discharge derived from the frontal sinus is highly suggestive of CSF leak. The presence of oedematous mucosa or a granuloma is also suggestive of CSF leak. A transparent pulsatile mass, sometimes covered by small vessels, is suggestive of meningocele.

Ethmoidectomy is recommended before opening the frontal sinus in order to identify the classical landmarks of functional

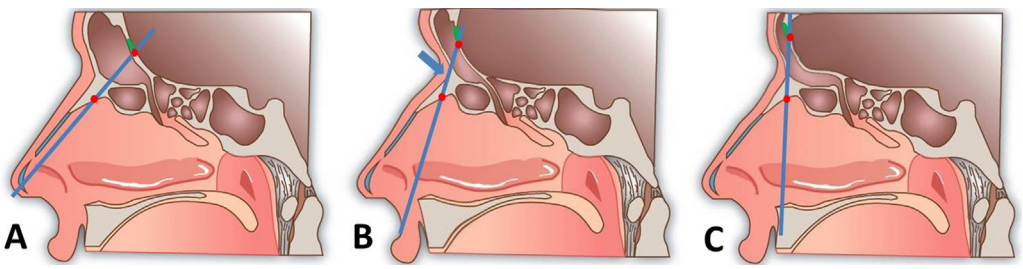

Fig. 3. Preoperative diagram (according to Sieskiewicz et al.). A. A line is drawn at the most anteroinferior part of the frontal sinus ostium and the inferior edge of the defect (green rhombus). Endoscopic repair is impossible if the line crosses the nasal bone (B, blue arrow), is tangential (C) or crosses the posterior wall of the frontal sinus before reaching the defect.

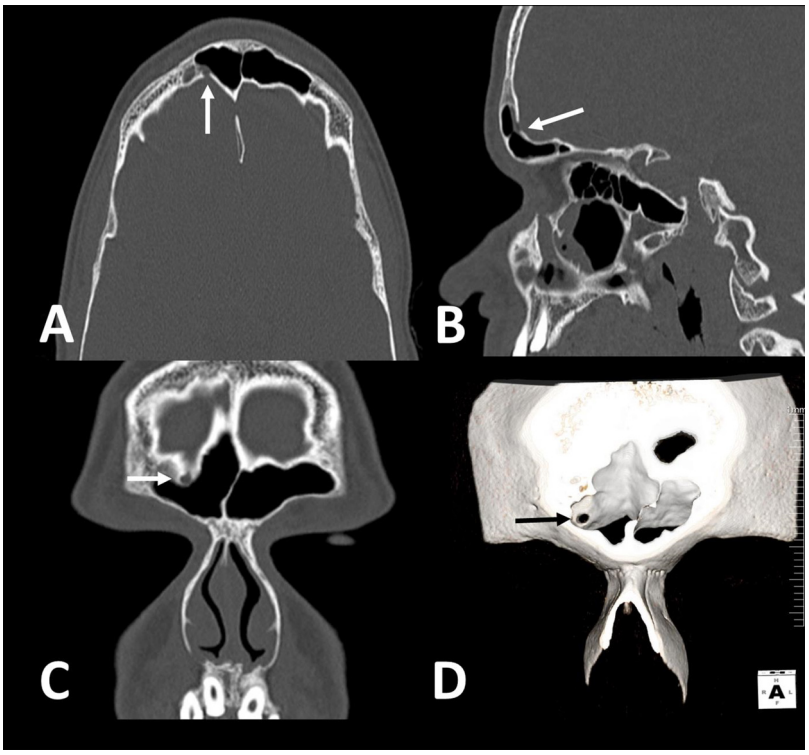

Fig. 4. Right lateral defect of the posterior wall of the frontal sinus. CT scan, (A) axial section, (B) sagittal section, (C) coronal section, (D) 3D reconstruction. Defect (black and white arrow). This patient required open surgery with an osteoplastic flap.

endoscopic sinus surgery. According to some authors, ethmoidectomy must be completed by sphenoidotomy to prevent the development of postoperative sphenoidal mucocele [11]. These two procedures also allow inspection of the skull base to identify any other CSF leaks. This surgery may be either unilateral or bilateral, depending on the site of the CSF leak in the frontal sinus: bilateral surgery should be preferred in the case of a medial CSF leak, while unilateral surgery may be sufficient for a more lateral CSF leak. Surgery is performed via the ipsilateral nasal cavity with the exception of lateral CSF leaks, for which access via the contralateral nostril may be more practical.

The choice of the most appropriate surgical approach depends on the site and size of the CSF leak as well as the available equipment and the surgeon's skill and experience. A thorough knowledge of frontal sinus anatomy is essential to obtain complete exposure of the defect: all anterior ethmoidal cells around the frontal sinus ostium, such as the agger nasi and posterior suprabullar air cells, must be opened to provide access to a CSF leak adjacent to or situated in the frontal recess (type 1 and 2 according to Schlosser et al. and type A according to Shi et al.). If the instruments are unable to reach the defect after complete opening of the frontal recess, frontal sinusotomy must be performed. The extent of the sinusotomy must be adapted to the type of CSF leak, and extensive frontal sinusotomy is not always necessary (Fig. 5). However, Draf type III sinusotomy provides better exposure of the posterior wall of the frontal sinus [10,16,20].

Once the defect or meningocele has been exposed, a 5 mm cuff of healthy mucosa is removed around the defect to ensure better adhesion of the graft and to promote osteogenesis around the defect. A meningocele is cauterized to allow retraction and tightening of the dura mater. If necessary, the meningocele can be resected [6]. In the case of fracture of the posterior wall of the frontal sinus, the mucosa situated on the fractured fragments is removed and involved bone fragments are reduced using a suction cannula to restore the contours of the posterior wall. In the case of a spontaneous CSF leak or meningocele, the bone around the defect is often very thin and must be handled very cautiously to avoid accidental enlargement of the bone defect, particularly in the case of BIH, where the posterior wall of the frontal sinus may be as thin and as fragile as an eggshell.

Maintenance of frontal sinus patency must always be a major objective when repairing a CSF leak. The type of graft and the graft placement technique are often guided by personal preference [25]. Repair material can consist of: fat, muscle, bone or cartilage, fascia lata or temporalis fascia, free or pedicled mucosal flaps, collagen sponge (TachoSil, Baxter, Deerfield, USA), etc. Although many CSF leak repair techniques have been described, only a small number of principles, when correctly applied, are sufficient to ensure a high CSF leak repair rate [25–28]. However, none of these principles are mandatory [25,29]:

- meticulous resection of the mucosa around the defect;
- the first layer must be impermeable (fibrin sealant is used to ensure adherence of the various layers not to ensure a watertight closure);
- closure in several layers is preferable;
- grafts and mucosal flaps facilitate healing (but do not close the defect);
- maintain frontal sinus patency.

Whenever possible, the first layer must be placed as an intradural underlay in the presence of a large defect [28,30–32]. Fat, muscle, fascia or a dural substitute can be used [6]. A second layer can be placed extradurally, between the dura mater and bone. Fascia can be used to repair a small defect, but the use of a rigid graft, such as mastoid cortex, a fragment of vomer, the perpendicular plate of the ethmoid, middle nasal concha or septal cartilage, should be used to repair a defect larger than 1 cm. Jones et al. recommended systematic use of a bone graft to repair spontaneous CSF leaks or BIH, regardless of the size of the defect [10]. A mucosal

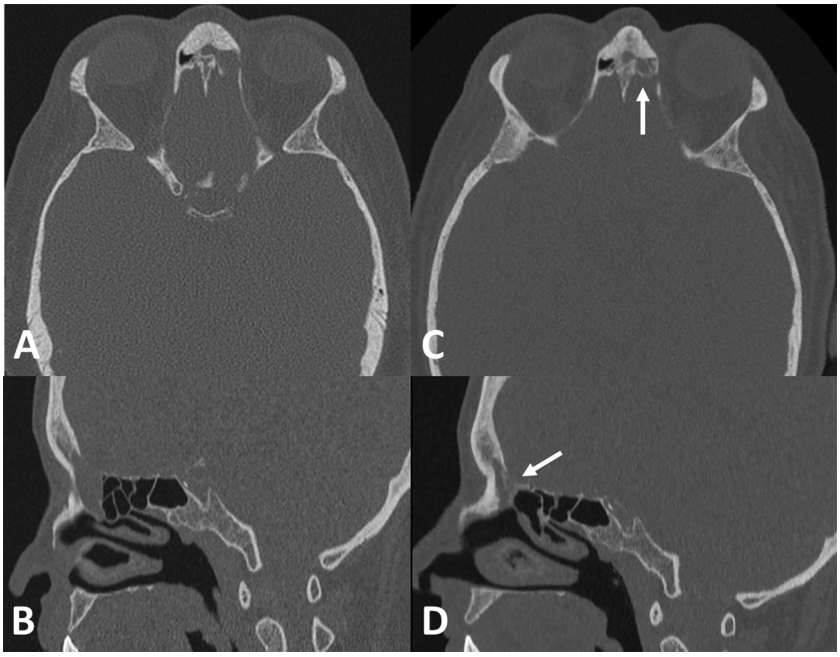

Fig. 5. Schlosser type 2 spontaneous meningoencephalocele. Preoperative CT scan, (A) axial and (B) sagittal sections. CT scan demonstrates the meningocele with a poorly pneumatized frontal sinus. This patient was operated by an exclusive endoscopic approach with closure by fat, cartilage and septal mucosa graft. Frontal sinusotomy and posterior ethmoidectomy were not necessary, as the frontal recess was widely opened by the lesion. CT scan, axial (C) and sagittal (D) views 2 years after surgery. CT scan shows complete re-ossification of the defect (white arrow), but with a fibrous scar in the frontal recess. The patient remained asymptomatic 3 years after surgery.

graft or pedicled mucosal flap (nasoseptal flap) can be used as a third layer, placed extracranially against the skull base (overlay) [8,10,13,16,33]. Fibrin sealant is very useful to ensure adherence of the various layers. Finally, a layer of Gelfoam (Baxter Healthcare Corporation, Hayward, USA) or Surgicel (Ethicon, Sommerville, USA) can be used to reinforce the grafts. A sheet of Silastic (Dow Corning Corporation, Midland, USA) [9,33] or a Raines frontal sinus stent (Smith and Nephew, London, GB) [17] is placed in the frontal recess to prevent obstruction. A nonresorbable nasal pack, such as a glove finger filled with Merocel (Medtronic, Minneapolis, USA), can be placed in the frontal recess to maintain patency and to allow less traumatic removal [34,35].

4. Postoperative care

No consensus has been reached concerning the need for postoperative antibiotics. However, most surgeons use an intravenous antibiotic active on Gram-positive cocci for 24 to 48 hours after the procedure [36,37]. Intravenous antibiotics can then be replaced by an oral antibiotic such amoxicillin/clavulanic acid until removal of nasal packs for one or two weeks after surgery [10,13,20,25]. Stents are left in place for 1 to 8 weeks [9,17,33]. When present, lumbar drainage is left in place for 2 to 7 days. Mannitol or acetazolamide can be prescribed. The recommended duration of strict bed rest varies considerably from one author to another, ranging from 1 day to 2 weeks, and mainly depends on the risk of recurrence of the CSF leak and the surgical team's usual practice [13,17]. Analgesics and laxatives are also prescribed. The patient must avoid carrying heavy loads and nose blowing. After returning home, patients are regularly reviewed to perform debridement of the nasal cavities to avoid prolonged crusting and synechiae.

5. Results and complications

Jones et al., who have published the largest series of endoscopic frontal sinus CSF leak repairs (37 patients), reported a closure rate after the first attempt of 91.9% with a mean follow-up of almost one year (51 weeks) [10]. Three of their patients required reoperation due to persistent leaks and two of them were successfully reoperated endoscopically, which gives an overall success rate of 97.3%. Shi et al. successfully treated 12 of their 13 patients (92%) by endoscopic surgery with a mean follow-up of 30 months [13].

The complications of endoscopic CSF leak repair were studied in the meta-analysis by Hegazy et al., but are not specific to the frontal sinus [29]. They consisted of meningitis (0.3%), brain abscess (0.9%), subdural haematoma (0.3%), olfactory disorders (0.6%) and headache (0.3%).

Acute complications specific to frontal sinus surgery are anterior ethmoidal artery injuries that can be responsible for immediate or late postoperative intranasal bleeding, or even intraorbital haematoma requiring emergency decompression [38]. A specific feature of the frontal recess is its narrow ostium, which is associated with a high risk of medium-term or long-term postoperative stenosis and therefore mucocele or frontal sinusitis [39]. Several factors contribute to these complications; some can be prevented, such as incomplete dissection of the agger nasi, persistence of ethmoidal or frontal air cells close to the frontal recess or cicatricial lateralisation of the middle nasal concha [40,41], while others are more difficult to prevent, such as neo-osteogenesis of the frontal sinus ostium or the presence of hypertrophic and oedematous mucosa [42]. Meticulous preservation of the frontal recess mucosa and possible frontal sinus stenting can help to decrease the risk of stenosis, which nevertheless remains high [43,44].

6. Conclusion

Endoscopic frontal sinus CSF leak repair requires a good knowledge of both the surgical techniques specific to the frontal sinus, such as Draf frontal sinusotomies, as well as the basic techniques of endoscopic CSF leak repair. Maintenance of frontal sinus patency must be a priority and must always be at the forefront of the surgeon's mind during the operation. When these conditions are observed, endoscopic repair is associated with a very high success rate and a low complication rate. The current limitations of this

surgery will very probably continue to decline as surgeons' experience, instruments and surgical techniques continue to improve.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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