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Obliteration of the frontal sinus – state of the art and reflections on new materials*

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SUMMARY *Despite increasing advances in endonasal frontal sinus surgery, obliteration of the frontal sinus is necessary in some cases for definitive clearing frontal sinus pathology. Reviewing the literature and considering pathophysiological aspects, successful obliteration of the frontal sinus depends on the complete removal of the mucosa and a sufficient closure of the nasofrontal duct, but not on the material used for obliteration, if special considerations are taken into account and foreign materials are avoided. Complete removal of the mucosa has to include removal of the inner bony cortex of the frontal bone. Occlusion of the nasofrontal duct is achieved with a sufficiently fixed fibrous layer.*

Key words: Osteoplastic frontal sinus surgery, obliteration, adipose tissue, magnetic resonance imaging

INTRODUCTION

Most conditions of the frontal sinus requiring surgery can be successfully managed by endonasal procedures (Close et al., 1994; Draf, 1991; Draf et al., 1995; Gross et al., 1995, Har-El and Lucente, 1995; Hoffmann and May, 1991; Hosemann et al., 1992, 1997a,b; Hosemann, 1996; Loury, 1993; Lund, 1995; May, 1991; May and Schaitkin, 1995; Metson, 1992; Perko, 1989; Rudert, 1995; Schaefer and Close, 1990; Weber et al., 1996, 1997a,b; Wigand and Hosemann, 1991). There remain, however, a number of problematic cases, where optimal exposure of the entire frontal sinus is mandatory, the natural drainage is irreversibly damaged, and possibly complete removal of the mucous membrane and obliteration are required. Such indications may be chronic frontal sinusitis which did not resolve after endonasal surgery, mucopyoceles caused by occluded frontal sinus drainage mainly after Lynch preoperations, severe fractures, especially such involving the drainage pathway, and tumours such as large osteomas (Kudryk and Mahasin, 1988; Mann et al., 1989; Myers and Hall, 1985; Wallis and Donald, 1988, Weber et al., 1994, 1995a,b).

The following principles are considered essential for successful sinus obliteration:

I. Meticulous removal of all visible mucosa and removal of the inner cortex of the sinus wall
II. Permanent occlusion of the nasofrontal duct
III. Choice of the appropriate material for obliteration

I. Removal of mucosa and the inner bony cortex

The complete removal of all mucosal remnants is mandatory because mucosal remnants cause subsequent growing of mucoceles (Hilding 1933a,b; Hybels and Newman ,1977; Schenck, 1975; Walsh, 1943), which could occur 10, 20 and even up to 40 years after the initial mucosal injury (Newman and Travis 1973, Helmy et al 1990). Therefore, meticulously stripping the mucosa from the sinus walls is not sufficient. The inner cortex of the frontal bone has to be removed with a burr (Hilding, 1933b; Montgomery and Pierce, 1963; Montgomery, 1964; Schenck, 1975; Walsh, 1943).

Montgomery (Montgomery, 1964; Montgomery and Pierce, 1963) advocates removal of the inner cortex of the frontal sinus walls with a cutting burr, both to ensure complete removal of the mucous membrane and to increase the blood supply to autogenous implants used to obliterate the sinus.

Donald (1979) performed obliteration of the frontal sinus in 27 cats. He dissected the mucosa meticulously with a sharp eleva-

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tor under microscopic control and curetted the cavity with a stapes curette. The mucosa of the nasofrontal duct was inverted on itself. Material for obliteration was fat, collagen or none. At two, seven, nine and twelve months postoperatively he found that only 6 cats had no evidence of inflammation. Obliteration was complete in only ten of the 54 sinuses (18%). Epithelial regrowth occurred very often. Donald concluded that his experiments clearly showed that if excision of the inner cortical layer is not performed the epithelium regrows with startling rapidity. He demonstrated on histological examination how the mucosa dips into the small vascular pits that pockmark the bone. This provided a clear explanation of why the actual excision of bone is required to rid the sinus cavity of all vestiges of mucosa. Coates and Ersner (1971) saw in their experiments on dogs mucosal regeneration after curettage of the mucosa only.

Hybels and Newman (1977) performed experiments using cats to examine the natural history of posterior table fractures of the frontal sinus and the methods available for treatment. They found at 6 months postoperatively that mucoceles had formed when the nasofrontal duct was plugged or mucosa is inadequately removed during obliteration, not using a burr.

Comment

There is no doubt that complete removal of mucosa is mandatory. The safest way to achieve this is removal of the inner bony cortex using a burr. It may be that in an unknown number of cases removing with elevators and curetting of the bony cavity may be sufficient because some clinical series using this method did not report worse results than others (reports on MacBeth-operations, see below).

The validity of these reports is limited, however, because imaging of the obliterated sinus did not include CT or MR. *Therefore using a burr to remove the inner bony cortex has to be defined as standard and integrated part of an osteoplastic procedure with obliteration.*

The use of a cutting burr in animal experiments did not correspond with the clinical situation in many cases where dura mater or periorbit are widely exposed because of bony defects of the posterior wall or the orbital roof. In these cases the use of a diamond burr is recommended and mandatory to avoid dural lesions or major orbital complications like orbital hematoma with blindness, injury of ocular muscles (Weber et al., 1994, 1995a). Microscopic control is recommended to be adequately sure that all recessus are cleared from mucosal remnants (Goodale and Montgomery, 1964; Tato et al., 1954; Weber and Draf, 1994, 1995a).

Bright et al. (1983) investigated 4 cats 200 days after fat obliteration. They wanted to prove whether complete removal of the mucosa is possible without intraoperative magnification by using a burr and plugging the nasofrontal duct with temporalis muscle. In 3 of the 4 cats they found remnants of mucous membrane and concluded that a dissecting microscope or some form of magnification would be necessary.

The microscope is sometimes difficult to handle far posteriorly for large supraorbital recessus or far laterally for lateral recessus. Using magnifying glasses provides a better overview and saves much time ensuring the same safety of complete removal of mucosal remnants. *The result will not depend on the choice of microscope or loupe magnification but on the thoroughness of the operation. Therefore, the surgeon should choose the magnifying device which is available and which he is used to deal with.* In some cases it will be necessary to remove at least parts of the posterior wall of the frontal sinus and to retract the exposed dura in order to get sufficient access to a deep supraorbital recess.

II. Permanent occlusion of the nasofrontal duct

Experimental and clinical studies have shown the impact of incomplete occlusion of the nasofrontal duct, resulting in failure to achieve complete sinus obliteration. Successful frontal sinus obliteration depends on complete and permanent obstruction of the nasofrontal duct too (Abramson and Eason, 1977: Schenck , 1975). Schenck (1974) made experiments on 6 dogs occluding the nasofrontal duct from below without further surgery on the sinus itself. Two to six months after surgery he found failure of the intended obstruction in 2 cases. The other sinuses were filled with viscous fluid without any sign of infection or mucosal cysts. Schenck (1975) found that intentionally leaving a strip of mucosa leads to failure of obliteration by osteoneogenesis 100 percent of the time. Sinus obliteration was much more consistent with concurrent closure of the nasofrontal duct.

Closure of the nasofrontal duct could be achieved by inverting the mucosa and plugging the ductal opening with fascia or periosteum and fat (Tato et al., 1954), fascia (Luce, 1987; Sessions et al., 1972), muscle (Disa et al., 1996; Donald and Bernstein, 1978; Luce, 1987; Matras and Kuderna, 1980; Nadell and Kline, 1974), or bone (Grahne, 1971; Knauff, 1963). Regardless of the method used, obliteration of the nasofrontal duct seals of the sinus cavity and should prevent ascending infection from the nose and regrowth of mucosa from the duct as described by many authors. Catalano et al. (1991) wrote, that it is imperative to occlude the opening of the nasofrontal duct with fat, muscle, and /or bone to prevent regrowth of sinus epithelium from the nasal cavity or distal nasofrontal duct.

Comment

There remain, however, some questions, whether a special closure of the duct is really necessary and what are the true reasons for failure in experimental sinus obliteration without closure of the duct. It is conceivable that small fat pieces slide down into the nose via an open nasofrontal duct, thus open up a cavity in the supposed completely obliterated frontal sinus in which mucosal ingrowth can occur. This phenomenon has not been investigated till now. The theory of retraction of the transplanted material seems more unlikely remembering the physiology of wound healing (Chapvil and Koopman, 1984: Clark, 1991; Cohen et al., 1992; Porras-Reyes and Mustoe, 1994; Reed and Clark, 1985; Wahl and Wahl, 1992; Zitelli, 1987). If the mucosa is completely removed in the sinus itself mucoceles cannot occur at any location. It is possible, however, that after three weeks, reorganisation of collagen fibrils of scar tissue leads to some retraction of the implanted tissue. But this process is a very slow one, the amount of retraction will not be very high from a physical standpoint, and it will not occur irregularly. This retraction will lead to a stepwise formation of a small bulging of the nasal cavity into the cranial parts of the nasofrontal duct or the caudal parts of the frontal sinus.

The small cavity is lined by stepwise growing mucosa and will not be irregular in shape and will not form any mucocele. This is supported by the findings of Hybels and Newman (1977) who examined the extent of mucosal growth into the sinus when the nasofrontal duct is not plugged in a fat-obliterated sinus (2 animals). In these instances, the mucosa grew in as far as the fat graft, forming a blind pouch which drained into the nose without consequence.

Several clinical reports did not find recurrences more often though they did not treat the nasofrontal duct in a special way to achieve permanent closure (Goodale and Montgomery, 1964; Hardy and Montgomery, 1976; MacBeth, 1954; Montgomery, 1964). Clinical series with controlled comparison of both techniques, only inverting the duct mucosa and closure with a special material, are not available till now.

It seems therefore meaningful and is recommended to close the duct with some sort of material which forms a fibrous layer, which separates the obliterated cavity to prevent mainly a sliding-down of implanted material and secondarily an circumscript ingrowth of mucosa. The closure technique of Weber et al. (1994,1995a) with downward inverting of the mucosa, plugging the opening with cartilage (harvested from the ear, septum or allogenic cartilage) as a self-retaining plug and covering this plug with allogenic dura is very efficient and stabile, but could be an overtreatment for many cases. In most cases a widely covering layer of fibrous tissue such as temporalis fascia, galea-periosteum or allogenic dura is sufficient if it does not slip down into the nose.

This will occur only in very large openings and is prevented by covering both sides with one piece and by a wide-overlapping which fixes the transplant by adhesion and cohesion forces. The fibrous tissue should be 1 cm larger than the opening of the nasofrontal duct in each direction. We prefer allogenic scia lata (Tutogen Medical, Erlangen, Germany) which is easier to handle and sits very stabile because of its stiffness and which is approved for duraplasty by the “Bundesinstitut fur Arzneimittel und Medicalprodukte” . On the basis of current knowledge transmission of infection, particularly by unconventional viruses, can be ruled out (Diringer and Braigh, 1989).

There was no report on any endangering of patients up to now (Liebeherr and Schöpf, 1998). Additional use of fibrin glue makes the fixation secure. It does not seem to be necessary to resect muscle from the supraorbital region (Disa et al. 1996) with some donor-site morbidity for closure of the nasofrontal duct. The influence of a postoperative infection by special closure technique has not investigated till now and seems to be minor.

III. Choice of the appropriate material for obliteration

There are two main techniques of obliteration: spontaneous obliteration which means filling the cavity by own blood and obliteration with autogenic material. The most popularised is freshly harvested abdominal fat. Cancellous bone or muscle are further materials for obliteration. The use of other materials is only described in individual publications and have not gained broader acceptance.

A. Spontaneous obliteration

This was reported long ago by Samoilenko (1913), who found an obliteration by osteofibrous ingrowth in an experimental study on cats and dogs. Hilding (1933b) and Walsh (1943) confirmed the obliteration with partially ossified scar tissue in the canine and dog frontal sinus. Hilding and Banovetz (1963) established that fibrous tissue in a spontaneoulsy obliterated canine frontal sinus is subsequently replaced to a variably degree by cancellous bone. Gibson and Walker (1952, 1954) and MacBeth (1954) popularised the technique of frontal sinus obliteration by (spontaneous) osteoneogenesis in Great Britain. They did not use the operating microscope and the nasofrontal duct was not occluded. MacBeth (1954) reported on 16 patients which relieved completely or almost completely 1 year after the operation.

He did not use a burr to remove the mucosa. Bosley (1972) described a series of 100 consecutive patients operated on by MacBeth with a follow-up ranging from 5 months to 13 years. He found a 3 percent incidence of acute sinusitis which corresponded to medical management and radiographic evidence (Waters view) of incomplete obliteration in only 7 percent. Eighty-five patients were completely satisfied, 15 continued to have frontal headache. Four patients had to be revised.

At long-term follow-up Bordley and Bosley (1973) found 4 recurrences after spontaneous obliteration in 22 cases and 2 recurrences after fat obliteration in 6 cases. Morgan and Robinson (1973) reported on 10 cases with spontaneous obliteration, 5 of which had indwelling frontonasal tubes. All were symptomatically cured without any recurrence. There were 2 intracranial complications due to surgery. Middleton et al. (1985) described 21 patients 1 to 10 years after MacBeth operation. One case had to be revised because of a recurrence, in one additional case the cosmetic result was unsatisfactory.

B. Autogenic material

B1. Fat.

The technique of obliteration with freshly removed abdominal fat goes back to Bergara (Bergara, 1950; Bergara and Itoiz, 1951; Bergara and Itoiz, 1955) and Tato et al. (1954). Particularly after the reports by Goodale and Montgomery (Goodale, 1963, 1965; Goodale and Montgomery, 1958,1961, 1964; Montgomery, 1964,1967) osteoplastic frontal sinus surgery with fat obliteration has been established as “gold standard” in managing the difficult frontal sinus.

Experimental investigations on the efficiency of fat obliteration and the fate of implanted adipose tissue

Bergara and Itoiz (1955) made experiments on 31 dogs with obliteration of the frontal sinus with fat, comparing freshly harvested autologous graft boiled fat in an isotonic sodium chloride solution, and bank fat. They found a replacement by connective tissue in the boiled adipose tissue, but the fresh autograft had the aspect of normal adipose tissue. A connective tissue capsule of 1 mm fixed it to the osseous wall. Clinically he reported on 34 cases (20 with fresh autograft, 9 with adipose tissue from a "fatty tissue bank", 5 with a mixture of fat from a bank and blood clot) where he obtained very good results, with the exception of 2 cases needing revision surgery. From their experience in operating suppurative disease and the histologic investigation of two revision cases they concluded that the fatty implant resists infection in the same way as any other connective tissue. Montgomery and Pierce (1963) performed experiments on 3 cats, investigated one month after fat obliteration, three months after fat obliteration and 6 months after obliteration with Gelfoam respectively. After fat obliteration the sinuses were completely obliterated and the mucosa removed, the cats asymptomatic. From clinical experience and animal experiments they concluded that adipose tissue seems to resist infection. "None of our experimental adipose implants have become infected" (according to this paper there were 2 implants). Montgomery (1964) reported on 9 animals which were investigated from 1 week to 12 months postoperatively. He found no regrowth of mucosa after removing the inner cortical layer of the bone with a cutting burr and microscope without special occlusion of the nasofrontal duct.

The percentage of surviving tissue did not seem to be related to the duration of the experiment and ranged from 30% to 100% with a replacement of the rest of the adipose tissue by fibrous tissue.

This was supported by Hybels and Newman (1977) who did not find any infection 6 months after fat obliteration in cats. The survival of adipose tissue was not complete. Montgomery (1967) investigated the effect of fat obliteration of the frontal sinus on osteoneogenesis. In 20 cats he found at 4 to 8 months after the operation extensive osteogenesis in unimplanted sinuses accompanied by mucous membrane regeneration (mucocele formation). No osteogenesis occurred in association with adipose tissue implantation.

After fat obliteration in 4 frontal sinuses of cats Bright et al. (1983) found viable adipose tissue 200 days after the operation (40-50% in two cases), replacement by mixed fibrous-adipose tissue or bone ingrowth (10-30%). Owens and Klotch (1993) found a fat volume reduction and fibrous tissue replacement over a 3- month period when fat was used for both nasofrontal duct and sinus obliteration. Donald and Ettin (1986) investigated obliteration with fat when sinus walls are missing. The mucosa was removed using a cutting burr under microscopic control, and the nasofrontal duct mucosa inverted into the nose. After three months they found high rates of re-epithelialisation (37%), mucocele formation or infection (44%). They emphasised that fat obliteration is dangerous when 50-100% of the anterior or posterior table are missing. In these cases cranialisation of the frontal sinus was recommended (Donald, 1982). They pointed out, that if the fat graft resorbs any retraction from the nasofrontal duct opens the door for the ingrowth of respiratory epithelium into the now unobliterated portion of the sinus. The behaviour of his frontal sinus fat implants was similar to that of free fat grafts in general, as described by Peer (1950,1956,1977). According to his experience with 60 free human autogenous fat grafts he favours the so-called cell survival theory. This means that some of the transplanted fat cells survive as living entities and that these cells collectively represent the fatty tissue ultimately remaining in the transplant. He noted a 40-50% loss in volume of free fat grafts placed in abdominal wall pockets. Fat cells that did not survive were replaced by fibrous tissue. Additionally walled-off cystic cavities occur containing free lipid from dead cells. Traumatised fat grafts lose much more weight and volume than gently handled transplants. He emphasised that the host site should be well vascularised, but all bleeding and even moderate oozing of blood must be controlled. Ligatures of silk, catgut, and other foreign material are to be avoided. If infection occurs, all or almost all of the graft will probably be lost. Smahel (1986, 1989) pointed out that in contradiction to earlier views, it is now established that fat cells show high metabolic activity. Additionally, a high degree of vascularisation is a characteristic feature. Adipose tissue consists of lobules separated by fibrous septa. The septa carry relatively large vessels and nerves, and capillaries are practically absent. A lobule consists of hundreds or even thousands of fat cells. Its blood supply comes through a vascular pedicle. After adipose tissue free grafting a considerable reduction in the volume of the graft is to be expected. Revascularisation is only partial in fat grafts. Oil cysts develop in areas that have not been revascularised, and the fat is gradually resorbed. Fat lobules damaged or severed on removal of the graft are likely to be lost. Incision of the graft increased the cut surface, so a greater number of fat lobules were affected. If fat grafts become necrotic the fat is not simply resorbed. It must be taken up by macrophages which absorb the cell debris and released fat as part of an acute degradation. A chronic degradation consists of confluence of dead cells in pseudocysts lined with flattened macrophages. Therefore a fat graft is a potential foreign body. The importance of maximum contact between implant and host tissues has certainly emerged quite clearly in these experiments.

Smahel et al. (1990) showed in an animal experiment that revascularisation of free adipose tissue grafts was augmented by transplantation to a freshly mobilised vascular bundle and a bundle prepared three days previously. The rate of healed adipose tissue was 10-35% without augmentation, 40-85%, and 90-95% respectively. In the latter group the survival rate was in some grafts only 40-80%. In some grafts revascularisation was delayed. This was due to the fibrin coating preventing close contact between implantation pocket and graft to a variable degree. All grafts showed a reduction in size of 25-30%. This reflects the loss of fat cells during the early days.

Saccogna et al. (1997) investigated the fate of autologous fat transplanted into vocal folds in the cat. Up to 8 months after injection they found a significant but variable volume of viable fat graft. Occasional foreign body giant cells were present within the fat. There has been extensive experience with autologous fat transplantation in various areas of the body. In a particularly good review Billings and May (1989) summarise the literature on this subject and address many of the problems that take the use of fat controversial. In particular, the final bulk of the graft and fate of the fat are notoriously unpredictable. Coleman (1997) emphasised the very atraumatic handling of the fat and the transplantation of intact parcels of fatty tissue, instead of fatty cells, to increase the rate of survival.

In summary, since more than 100 years free fat autografts have been used in humans to augment, repair, and substitute defects in many regions of the human body (Billings and May 1989). In a review of the literature, investigations in animals and humans showed quite unpredictable results, with wide variations in the resulting bulk of the graft. All microscopic studies showed early breakdown of fat cells with formation of cystic-like lipid deposits and the presence of a large host histiocyte infiltrate. Recent research favours the hypothesis of cell survival theory in fat autotransplantation. Hereby, the role of the preadipocyte can be postulated. The graft of mature adipose tissue with its connective-tissue stroma, when implanted, goes through an initial period of ischemia and inadequate nutrition. This could cause for many of the mature cells either necrosis or dedifferentiation into preadipocytes. When the blood supply adequately supplies oxygen and nutrients to the graft, the adipocyte precursor pool of immature preadipocytes could differentiate into mature adipose tissue, albeit of less volume (Billings and May, 1989).

Clinical report on osteoplastic flap surgery with fat obliteration

Goodale and Montgomery presented their experience several times (1958, 1961, 1964). First they reported on 7 cases 1-3 years postoperatively, in 1961 they described 31 cases. They noted no infection or recurrence and a lack of osteogenesis demonstrated by x-ray 5 years after surgery. Montgomery and Pierce (1963) described 61 cases of chronic sinusitis with only 1 failure. Marx (1913) was satisfied with fat obliteration, but he stated that the implanted fat would be destroyed and replaced stepwise.

McNeill (1966) obliterated the maxillary sinus with abdominal fat in 14 patients and reported satisfactory results. There were no further details on subjective or imaging findings. Calcaterra and Strahan (1971) reported on 24 patients with fat obliteration after burring the sinus and plugging the nasofrontal duct with fascia. For 23 patients, complete eradication of disease, with no known instances of recurrence, was achieved. In one patient reoperation was required. Alford et al. (1965) reported on obliteration of the frontal sinus with fat and occlusion of the nasofrontal duct with temporalis muscle in 10 patients. There were no postoperative complications and no recurrence of infection. They used a microscope and a dental drill. Valenzuela (1966) presented 2 clinical cases of traumatic disease of the frontal sinus which were successfully operated using fat obliteration. Follow-up was only 3 to 6 months. Zonis et al. (1966) presented 100 cases operated with the Montgomery-technique and reported a failure rate of 3%. They stated, that on the basis of a small number of re-operated cases, it appears that adipose tissue survives as such in the sinus and that an unobliterated cavity completely cleaned of its lining membrane may obliterate spontaneously with fibrous tissue. Sessions et al. (1972) reported on 53 patients operated on for a variety of indications, but unfortunately, less than half of whom were followed for more than 1 year. Postoperative infection requiring revision surgery occurred in 3.7%. There were no postoperative mucoceles. Three patients had a frontal embossment. Tomlinson and Schenck (1975) reported a successful fat obliteration in a cat. The most comprehensive series is that of Hardy and Montgomery (1976). Two hundred and fifty patients were investigated with a median follow-up of 8 years (3-19 years). The overall complication rate was 18 percent: 5.2 % abdominal wound complications, 3% acute postoperative infections with necrosis of implanted fat, 3% recurrent chronic sinusitis. There was no report on the occurrence of mucoceles. Four percent of 208 patients with obliteration of the frontal sinus had to be revised. Ninety-three percent of the patients had no significant symptoms, 6% persistent pain, 1% persistent neuralgia. Catalano et al. (1991) presented a series of 59 patients 1 to 9 years after osteoplastic flap procedure with fat obliteration. Postoperative CT scans were obtained in 48 patients, postoperative MR scans in eight patients. Five patients had recurrent frontal sinus disease requiring revision of their osteoplastic flap. Four additional patients (6.7%) required a cranioplasty secondary to frontal bossing or bone resorption. Other complications were elevation or rotation of the bone flap (4), infection of the fat autograft (5), subgaleal infection (2), osteomyelitis of the bone flap (2), postoperative traumatic fracture of the bone flap (1), abdominal wound infection (1), infection of the operative wound (1), and epidural abscess (1). 31 patients were totally asymptomatic. Symptoms lasted from 1 to 2 months in most patients, but persisted 2 to 9 years in 10% of the patients, despite a lack of objective evidence of recurrent disease. Loevner et al. (1995) investigated 13 patients (9-14 months postoperatively: 10; 32 months postoperatively: 1; 9 years postoperatively: 1; 12 years postoperatively: 1) using magnetic resonance tomography. They found 3 mucoceles. Weber et al. (1994, 1995b) evaluated 75 patients with a median follow-up of 3.8 years (6 months -14 years) after osteoplastic frontal sinus operation with fat obliteration in 31 cases. The overall aesthetic and functional outcome was excellent. Revision was necessary in one case only. The patient had forced air into the frontal sinus by blowing his nose too early so that there was threat of infection.

Evaluation of frontal sinus after fat obliteration using CT and MR imaging

Examination of the obliterated frontal sinus is insufficient without any clear imaging of the sinus content. Nowadays two precise imaging devices are available, CT and MRI. On CT low attenuation of the fat may be confused with air if the scans are only viewed at narrow (soft tissue) windows (Catalano et al., 1991). If viewed at wide (bone) windows, the airless nature of the completely sinus can be well seen. There is a range of normal appearances on CT that seems to represent various stages of partial fibrosis of the obliterating fat. In Magnetic Resonance Imaging the demonstration of even small frontal sinuses occurs artefact free. Partial volume averaging effects can be maximally eliminated by demonstration at multiple levels. The protons bound in fat show a short T1-relaxation time so that they are demonstrated as very light on the T1-weighted spin echo image. To limit comparable further processes with short T1-times (e.g. subacute bleeding) fat suppressant techniques can be put into force which act to selectively suppress signals from lipid-bound protons (Bydder and Young, 1995: Dwyer et al., 1988; Grossmann, 1996; Tien, 1992). On MR fat typically has a high signal intensity on T1-weighted images and an intermediate signal intensity on T2-weighted images (Catalano et al., 1991; Som 1991; Weisskopf and Edelman, 1996). The areas of fibrosis have low to intermediate signal intensity on both Tl weighted and T2-weighted scans (Catalano et al., 1991; Som, 1991). Infection of the fat is seen on MR as an overall high signal intensity on T2-weighted images (Catalano et al., 1991, Som, 1991).

Hyperintensity within the frontal sinuses on T2-weighted images and enhancement (peripherally and/or centrally where fat was replaced with soft tissue) were found to some degree in all patients (Catalano et al., 1991; Loevner et al., 1995). The degree of replacement of frontal sinus fat with soft tissue ranged from 4% to 85% (mean 43%, Loevner et al., 1995). Five of the 13 patients of Loevner et al. (1995) with persistent symptoms had no distinguishing MR features when compared with asymptomatic patients. Although increased T2-weighted intensity, fat replacement, and enhancement are findings compatible with inflammation, these changes may be seen in patients who are asymptomatic after placement of osteoplastic frontal sinus flap; they may present the normal granulation process. Most common imaging pattern was that of peripheral rim and central T2-weighted hyperintensity with associated peripheral or central enhancement.

It is the prevailing sentiment that postoperative granulation tissue and scar material are dynamic tissues that may have wide-ranging and variable intensity and enhancement characteristics. For example, central hyperintensity on T2-weighted images associated with enhancement on corresponding postcontrast T1-weighted images could represent granulation tissue or inflammation, whereas central hypointensity on T2-weighted images associated with enhancement may similarly represent scar tissue. The authors concluded that MR findings after osteoplastic frontal sinus flap replacement are non-specific and have limited utility in distinguishing symptomatic patients with recurrent inflammatory disease from asymptomatic patients whose imaging findings are related to postoperative scar tissue. The area where MR examination may prove to be most useful is in the early detection of mucocele formation in relatively asymptomatic patients.

The fat implanted into the frontal sinus of 11 patients aged 22-65 years having undergone an osteoplastic frontal sinus operation with obliteration was examined 4 to 24 months postoperatively by MRI (Keerl et al., 1995; Weber et al., l995c). Objectives were the time dependent distribution of portions of vital fatty or connective tissue, the eventual development of necroses or cysts as well as recurrences, inflammatory complications or re-epithelialisation of the frontal sinus. In only 6 of 11 cases so far, vital fatty tissue was found. Fatty necrosis occurred five times, whereas in 4 cases a transformation into granulation tissue and in one case into connective tissue could be seen. All 11 patients were complaint free. In a recent investigation (Weber et al.), 65 patients with fat obliteration of the frontal sinus were evaluated up to 10 years postoperatively. From 44 patients 70 examinations with MRI were available. A first analysis showed that the amount of tissue indicating viable fat cells decreased with time. There was no influence of the size of the frontal sinus on the survival of transplanted adipose tissue. A more detailed analysis is in preparation.

B2. Muscle

The use of muscle for obliteration is preferred by Alföldy (1965), Manson et al. (1986), Nadell and Kline (1974), Sataloff et al. (1984), and in standard neurosurgical texts (Wilkins and Odom, 1982).

McNeill (1967) found that muscle was as effective as fat in obliterating but was rapidly replaced by fibrous tissue. Mann et al. (1989) evaluated the condition of the frontal sinus 7-48 months (in average 24 months) after previous craniotomy. In 25 patients an obliteration using free grafted muscle was performed. In 16 cases they found re-aeration, in 5 cases signs of infection and in only 4 cases complete obliteration. They concluded that free muscle grafts implanted without removing the inner cortical layer were unreliable for obliteration. Muscle grafts will retract or will be extruded via the nasofrontal duct.

B3. Autogenic (corticocancellous) bone

Goodale (1955) reported on 8 patients who were successfully operated using autogenic bone to fill the defect after radical frontal sinus surgery. Knauff (1963) operated 6 patients successfully removing the mucosa with elevators and curettes under the microscope and invagination of the nasofrontal duct. The first two operations were performed in 1955. Complete bony obliteration after implantation of autogenous cancellous bone was confirmed later on (Hilding and Banovetz, 1963). Abramson et al. (1974) found that obliteration with autogenous cancellous bone and a frozen allograft resulted in total ossification in all 8 dogs after 12 months. Eason et al. (1976) performed experiments on the frontal sinuses of 12 canines filling the cavities with autologous cancellous bone 48 hours after infection with bacteria. One to three weeks after obliteration the sinuses were investigated. They concluded that the method was effective and bone transformation and obliteration will occur using an autogenous cancellous bone graft.

Clinical confirmation was provided by Grahne (1971) whose 11 patients showed radiographic evidence of complete frontal sinus ossification after a 5-year follow-up. All patients recovered well, all symptoms disappeared. He used a drill and the microscope and closed the nasofrontal duct with bone. According to Bassett (1972) removal of the inner bony cortex of the frontal sinus provides a good recipient bed that contributes to the long-term success of frontal sinus obliteration with cancellous bone. Plastic surgeons recommended obliteration with bone grafts too (Wolfe and Johnson, 1988). Goodale and Montgomery (1964) described bank bone as scaffolding, a framework, on which osteogenesis and fibrogenesis may take place. Cancellous bone undergoes a process of creeping substitution (Wilson et al., 1988; Manson, 1990; Gruss, 1982), acting as a scaffold for the formation of new bone. The implantation of an autogenic bone graft lead to a hematoma around the graft (Einhorn, 1996). Necrosis of the graft follows, and a local inflammatory response is stimulated. Within days, a fibrovascular stroma develops in which host-derived blood vessels and osteogenesis precursor cells migrate towards the graft. Although a few cells from the graft may survive the transplantation, the main contributions of the graft is its osteoconductive properties, any osteoinductive factors that are elaborated from it during the process of resorption, and the stimulation of an inflammatory response (Einhorn, 1996).

C. Other materials

There are only reports from individual authors and some more materials have been used in the past and will be tried in the future.

C1. Hydroxyapatite cement

It is a calcium-phosphate based material that when mixed with water forms a dense paste that sets within 15 minutes and isothermically converts in vivo to a microporous hydroxyapatite implant (Costantino et al., 1991, 1992). Six to twelve months after reconstruction of skull defects new bone was comprised in up to 77.3 % of the tissue replacing the cement (Friedman et al., 1991). Replacement is postulated to occur by a combination of osteoconduction and implant resorption. In nine cats Friedman et al. (1991) found no adverse reactions, infections, mucoceles, or implant extrusion 18 months after obliteration the frontal sinus.

C2. Glass ceramic (bioactive glass)

It has proved biocompatible and non-toxic and a useful bone-conducting material for occlusion of bone cavities (Peltola et al., l998). Peltola et al. (1998) did not find any adverse effects after obliteration with glass ceramic in 10 patients with chronic sinusitis over a mean follow-up of 5 years. Postoperative CT showed a slight yearly decrease in densitiy of the material. In one case a local infection in the anterior table occurred requiring revision surgery. The material was easy to handle and complete obliteration was easily achieved by different sizes of granules and blocks. They used a diamond burr for removing the mucosa, closed the nasofrontal duct with lyophilized dura and fibrin glue, and fixed the bone flap with titan miniplates. Suonpää et al. (1997) obliterated the frontal sinus in 20 patients with bioactive glass between 1990 and 1995. Only 1 had prolonged symptoms of the underlying chronic infection. Reinfection did not occur in any of the patients with glass ceramic but did in 6 of 19 patients obliterated with collagen matrix between 1982 and 1990. Wide et al. (1997) reported on a series of 31 patients with obliteration of the frontal sinus using bioactive glass (8 patients), collagen matrix (20 patients) or ossar (3 patients, see below).

Altogether 6 reobliterations had to be performed after a mean follow-up of 2 years, 2.7 years, and 6.7 years respectively. X-ray or CT, if available, revealed air in the sinus in none of 8 cases of glass-obliteration, 5 of 14 cases after collagen-obliteration, and none of two cases after ossar-obliteration. Because the nature of collagen matrix was not described in detail, a further discussion is not possible.

C3. Proplast

It is a Teflon fluorocarbon polymer and vitrous carbon fibers with pore sizes between 200mm and 500mm. Proplast can cause mild foreign-body reaction. Barton (1980) investigated 8 patients with chronic sinusitis 1 to 5 years after obliteration the frontal sinus with Proplast. The mucosa was removed using a diamond burr. There was no recurrence of infection, no mucoceles and no sign of rejection. In x-ray there was an appearance of likely connective tissue infiltration. The fibrous ingrowth occurs rapidly and acts to mechanically stabilize the material (Schenck, 1974). It does not increase or decrease in size after the implantation.

C4. Gelfoam

It leads to rather extensive osteogenesis and fibrous tissue replacement, and mucosal ingrowth too (Montgomery and Pierce, 1963; Montgomery, 1967). There is no larger patient series available.

C5. Gelitta

Fleischer 1978 reported on 2 patients 5-6 years after surgery. The cosmetic result remained satisfactory and ossified obliteration of the sinus was demonstrable radiologically. They were symptom free.

C6. Ionomer cement

Two years after obliteration in cats Baier and Datzert (1997), and Datzert and Baier (1997) found no evidence for mucosal regeneration or foreign-body reaction. Osteoid represented 43.5%, connective tissue 10.7% and ionomeric cement 45% of the whole cavity. They recommend the ionomer-based micro-implant because of its biocompatibility and biostability. Because of severe complications after using glass ionomer cement next to dura mater this material has been taken off the market.

C7. Ossar

It is a protein-free preparation from cattle bone (Siirala, 1967) used in 4 cases without postsurgical complications. Wide et al. (1997) described 3 cases in their series of 31 cases with frontal sinus obliteration. Later one patient underwent two reobliterations, the last of which with bioactive glass.

C8. Plaster of Paris

It consists of calcium sulphate which should be absorbed by macrophages and replaced by host bone (Beeson, 1981: Coetzee, 1980).

C9. Bone bank

Draf (1997) performed an osteoplastic flap operation with obliteration of the frontal sinus and reconstruction of the whole frontal contour using a femur head from the bone bank of the orthopedics. During the follow-up of 1 year the patients is symptom free and the esthetic result is excellent. CT showed a complete bony obliteration without any sign of delayed complication.

DISCUSSION

To obtain an overview on the significance of osteoplastic surgery with obliteration of the frontal sinus we performed a survey at the major ENT Departments in Germany. Most of the ENT hospitals are not very familiar with this kind of frontal sinus surgery. Our numbers of obliteration are significantly higher because many hospitals send their worse frontal sinus patients to us for definitive clearing. Most of the hospitals performing obliterations take abdominal fat for obliteration but do not occlude the nasofrontal duct with a specific layer (Table 1).

Table 1. Survey on osteoplastic frontal sinus surgery with obliteration in Germany.

		Number of departments	ENT Fulda (Number of operations)
Number of operations within the last two years	0	47	
	1-5	30	
	6-10	7	
	11-20	2	24
	(198)	1	
Material for obliteration	Abdominal fat	30	18
	Muscle	2	
	Spontaneous	5	
	Others	3	In case of small sinuses Own Blood: 2 Galeaperiosteum: 2 Collagen sponge: 2
Occlusion of the nasofrontal duct	No special material	24	6 (in cases of complete occlusion)
	Cartilage	6	
	Cartilage and dura		12 (cartilage from the ear=2)
	Dura		5
	Fascia	6	
	Galeaperiosteum		1
	Bone	2	
	Muscle	1	
	Fat	1	
	Fascia + cartilage		
	Allogenic material (included above)	(3)	(17: dura = 17 and cartilage = 10)

Material for successful obliteration of the frontal sinus has to fulfill the following properties or criteria (Table 2):

- It should be available at any time and in any amount
- It should be easy to handle There should be no or only minor morbidity to get the material (donor-site morbidity)
- It should not cause any foreign-body reaction
- Any transmission of infectious diseases (bacterial infections, HIV, slow viruses, ...) must be excluded
- It should not cause any toxicity
- It should not have any influence on follow-up examinations, particularly on CT and MRI
- It should be economic material, that means cause no or minor costs or minor time to prepare.

Despite an overwhelming acceptance, fat has some disadvantages as obliteration material. We have a significant donor-site morbidity with a visible scar at the abdominal wall, the risk of hematoma or seroma (> 5%) and infection. The appearance of the scar could be minimized if the incision is made in the inferior circumference of the belly-button (recommendation by Hosemann, personal communication). Some controversies may arise from different results of experimental investigations regarding the fate of transplanted fat. In some earlier examinations there is a lack of systematic investigation, and the number of presented cases is too low to draw certain conclusions. Summarizing all available investigations it is obvious that the transplanted fat remains viable in varying degrees with a large range from approximately 0% to approximately 100% (Figure 2). Necrotic cells will be absorbed and replaced by granulation and later on fibrous tissue or will form oil cysts (foreign-body reaction). Healing of the transplants varies depending on the characteristics of the recipient site where revascularisation starts on the fourth (Smahel, 1989; 1990) to seventh (Donald and Ettin, 1986) day at the periphery. Healing is better if fat is harvested freshly, if desiccation is avoided (it could be stored in a small container with a wet gauze pad on it – wash out by putting it in saline solution is probably unfavourable), if traumatisation is minimized (one large piece is better than several small, cut pieces), and a close contact between implantation bed and graft is realized (fibrin coating seems to reduce revascularisation) – "the health of the fat within the sinus is dependent on its close apposition to the intact osseous sinus walls" (Loevner et al., 1995). The statement that burring increases the blood supply to the adipose implant (Goodale and Montgomery, 1964) is unproved. The cutting burr which is recommended opens up vascular canals with subsequent bleeding into the sinus. This lead to a major fibrin clot between bony wall and adipose implant which deteriorates the healing rate (Smahel et al., 1990). Thus, the use of fibrin glue to clot the adipose implant have to be reexamined. If the diamond burr is used which is necessary when bony walls are thin or missing, vascular canals are closed with an unknown effect on the healing rate of transplanted fat. Nevertheless, it is very important to realize that there is no evidence in any study that the clinical outcome is influenced by the degree of surviving fat cells. The clinical result is independent of the viability of the implanted fat ! Furthermore there is some overlapping in

Table 2. Criteria and properties of materials for obliteration of the frontal sinus.

Method of obliteration →	Spontaneous	Fat	Muscle	Bone	Foreign material*
Properties ↓					
Available at any time and amount	+	+	+	+	(+)
Easy to handle	+	+	+	(+)	(+)
No donor-site morbidity	+	–	(+)	– + (bank bone)	+
No foreignbody reaction	+	(–)	+	+	–
No transmission of infection	+	+	+	+ (+) bank bone	+ (alloplastic)
No toxicity	+	+	+	+	(–)
No influence on follow-up	+	+/–	+	+/–	+/–
No additional costs	+	– (special instruments for harvesting)	+	+/–(special instruments for harvesting)	(–)
No prolongation of operation time	+	+ (second team) –	+	+ (second team) –	+

+ material fulfills this criterion; – material does not fulfill this criterion, devaluation; () limitations, see text; +/– two different aspects, see text.

appearance on MR imaging with mucoceles. The signal characteristics of mucoceles are variable, according to the protein concentration of the secretions (Lanzieri, 1996; Som, 1991). Usually mucoceles show low signal intensity on T1-weighted images, intermediate signal intensity on proton density weighted images and high signal intensity on T2-images (Som 1991). However, depending on concentration of proteinaceous secretions T1 signals could be low, intermediate or high, and T2 signals remain high in most lesions but could also be low (Lanzieri 1996, Lloyd et al. 1987, Som 1991). The appearance of transplanted fat on MR imaging is changing (Figure 1). Fat often forms roundly structures, which could be lobules of viable fat or small oily cysts or some granulation areas. Because of the varying signal intensities of both, mucoceles and fat, early forms of mucoceles are sometimes masked and will be diagnosed with some delay. At last, costs arise because the operation time is prolonged by harvesting the fat or an additional team is necessary to work parallel.

Muscle will be replaced by fibrous tissue and does not cause any foreign-body reaction. If it is harvested from the temporalis muscle only minor donor-site morbidity will occur and the operation time is hardly influenced. Interference with MR imaging regarding mucoceles does not occur.

Harvesting autogenic bone, e.g. from the iliac crest causes significant donor-site morbidity. If bank bone is taken special instruments to prepare the bone are necessary. Transmission of infections are extremely unlikely, but could not be excluded absolutely. Implanted bone will be replaced by bone. It may be

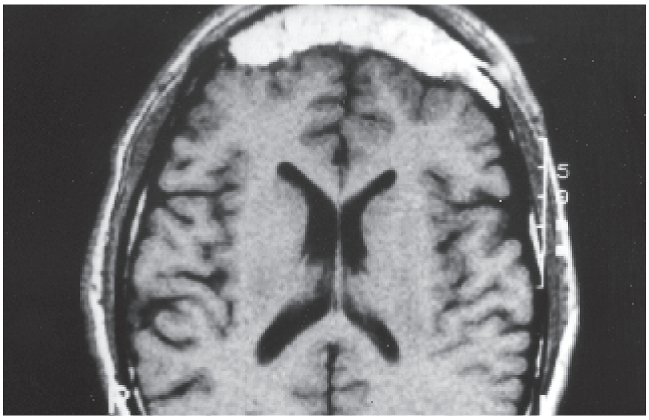

Figure 1a: MR imaging after frontal sinus obliteration with a fat autograft.

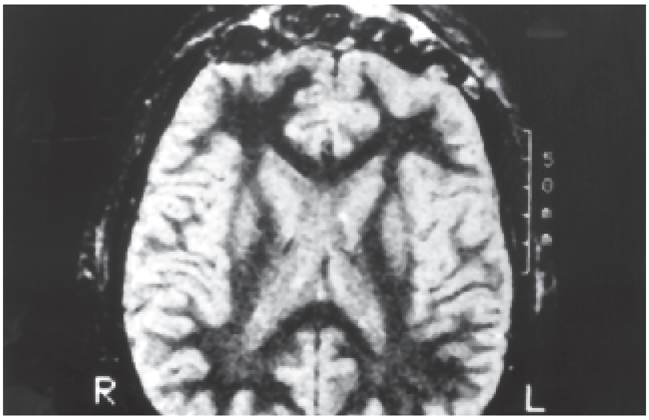

Figure 1b

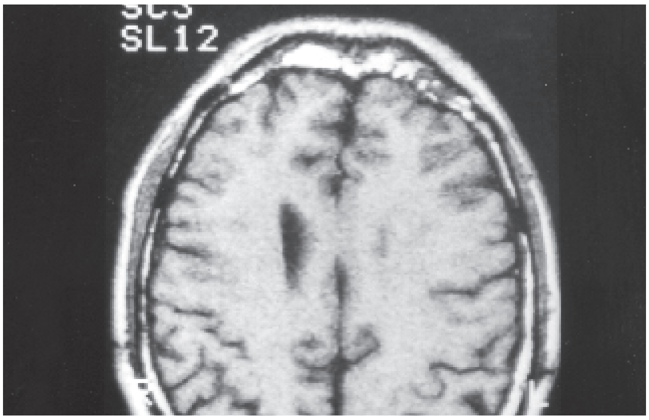

Figure 1c

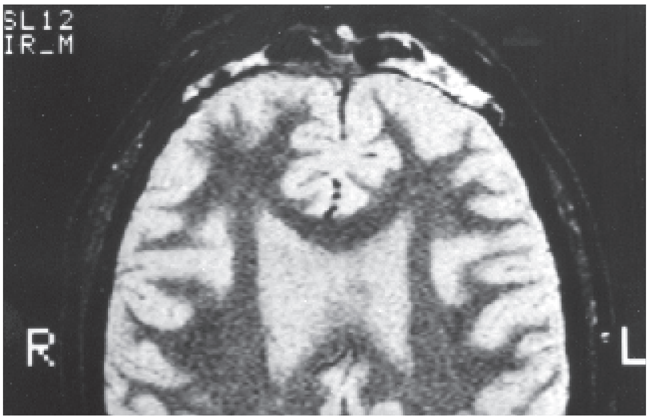

Figure 1d

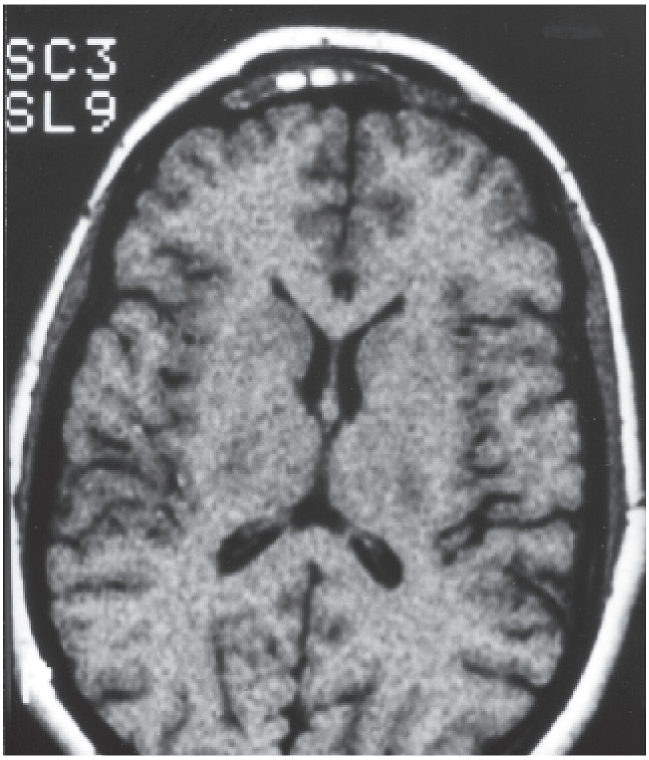

Figure 1e

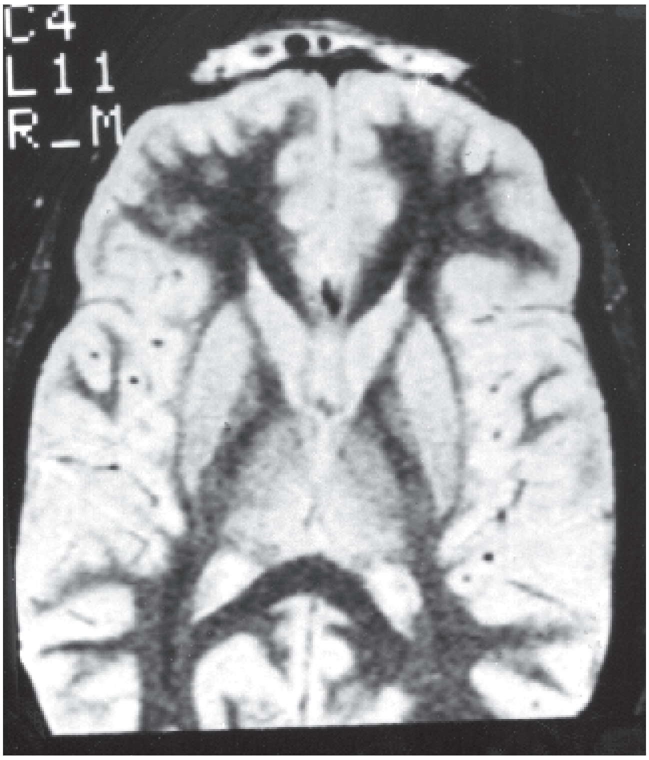

Figure 1f

Fig. la (T1 weighted) and Fig. 1b (STIR, fat suppression) show adipose tissue 3 months after transplantation which seems to be greatly viable, but forming round structures. 1 year later (Fig. 1c = T1 weighted and Fig. 1d = STIR) the amount of viable adipose tissue has decreased and it is replaced by fibrous tissue. Only a minor amount of adipose tissue is visible 6 months after obliteration in another patient (Fig. le = Tl weighted, Fig. lf= STIR), again forming round structures like an oil (pseudo)cyst or a lobule of adipose tissue.

difficult to define the adequate amount of bone implant in the case of missing walls towards the orbit and the anterior cranial fossa. There will be some risk to put in too much bone with compression of the orbit. There may be further problems if a mucocele forms posteriorly. First, a development towards the orbit and brain is to be expected because of less resistance. Second, it is much more difficult to operate this mucocele because of the thick bone mass in front of it. Materials like hydroxyapatite or bioactive substances which induce new bone formation and which will be degraded open up new horizons, particularly in combination with growth factors. They seem to be superior regarding donor-site morbidity, but the other disadvantages of bony material are the same and the costs will probably very high. Foreign material represents a foreign body in every case and carries the risk of early and late infection with the need of removal of the material. Any material carries the risk of long-term bioincompatibility or toxicity which are unknown to date. Therefore foreign material should be avoided particularly if sufficient autogenic material is available.

Rohrich and Mickel (1995) stated that an extensive review of the literature on frontal sinus obliteration suggests that the material placed inside the sinus is not as important as the surgical steps followed to prepare the sinus cavity prior to implantation of the graft. Mickel et al. (1995) compared four treatment groups (seven cats per group) specifically of implantation of autologous fat, muscle, and bone and spontaneous osteogenesis, using a strictly standardized operative technique in an unfractured, uninfected feline frontal sinus model. The operation included

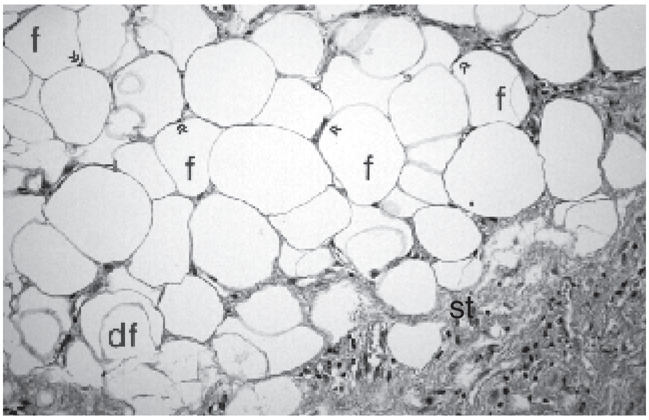

Fig. 2a: We can see young scar tissue with collagen fibres and a moderate cellular infiltration (st = scar tissue), viable fat cells with round empty cavities and a flattened nucleus at the periphery (f = fat cell,→ = nucleus) and some necrotic fat cells which loose there original appearance and confluence (df = dead fat cells).

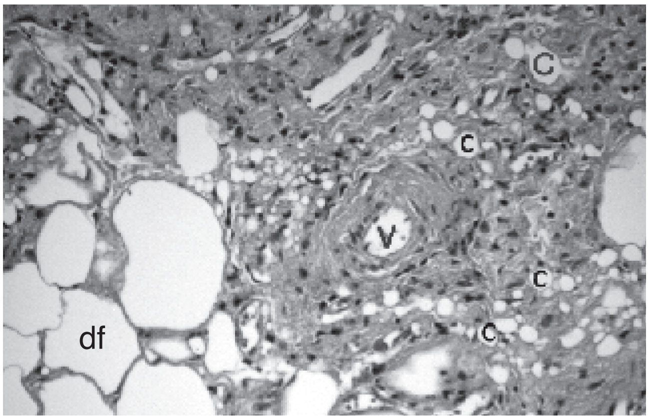

Fig. 2c: We see necrotic adipose tissue, the fat cells loose their round form and did not show any nucleus (df = dead fat cells). Within the granulation tissue there are many small empty cavities, smaller than original cells. Theses are small oil cysts(c = oil cysts). V = nutrient vessel.

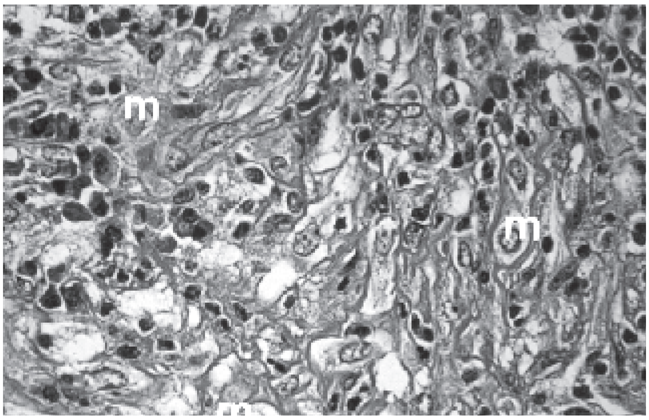

Fig. 2b: Acute degradation of adipose tissue. Necrotic fat cells are taken up by histiocytes/ macrophages (m = macrophages ingesting fatty tissue) and will be replaced by fibrous tissue. There are some collagen fibres and a major cellular infiltration.

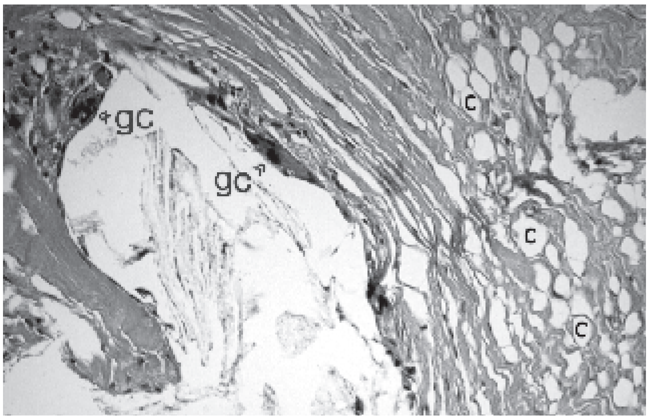

Fig. 2d: Chronic degradation leads to dead cells forming oil cysts of varying size (c = oil cyst), cavities without nucleus. We find many small pseudocysts without any significant actual cellular reaction in the surrounding tissue. A large pseudocyst appears as cholesterol granuloma visible by cholesterol crystals within the cyst. It is surrounded by foreign body giant cells (gc = giant cell).

Figure 2: Histologic examination of fat autografts after frontal sinus obliteration. Figures 2a-2d show different patients.

removing the mucosa and the inner bony cortex using a 3.5× loupe magnification and a cutting burr. The nasofrontal duct was occluded using temporalis fascia. All methods studied were effective in complete sinus obliteration 3 months postoperatively. Fat was viable in 86% evidenced by the presence of nuclei and vascular ingrowth, muscle showed fibrosis in 100%, bone led to new bone in 86% and spontaneous osteoneogenesis occurred in 100% with fibrous tissue ingrowth. There were no clinically significant sinus infections. However, significant morbidities occurred at the donor sites when autologous tissue transplantation was used. Therefore, spontaneous osteogenesis appeared to be the method of choice for the authors. Indeed, only spontaneous obliteration fulfills all criteria for an obliteration in a positive way (Table 2). There is some fear of first, infection of an frontal sinus filled with blood, and second, retraction with subsequent ingrowth of mucosa.. First, there is no proof of a significant higher rate of postoperative infection. A peri-operative application of antibiotics will drop the number of bacteria available for superinfection, will accumulate in the sinus via bleeding, and will have an effect in the blood clot against existing bacteria during the first day. Second, retraction which will occur in a minor amount is no problem for the development of mucoceles as lined out above (see comment to II. Permanent occlusion of the nasofrontal duct).

CONCLUSIONS

Despite increasing advances in endonasal frontal sinus surgery, obliteration of the frontal sinus is necessary in rare cases for definitive clearing of sinus pathology. Reviewing the literature and considering pathophysiological aspects successful obliteration of the frontal sinus depends mainly on the complete removal of the mucosa and a sufficient closure of the nasofrontal duct and only to a minor degree on the material used for obliteration as long as autologous material is used and foreign materials are avoided. Complete removal of the mucosa has to include removal of the inner bony cortex of the frontal bone. Occlusion of the nasofrontal duct is achieved with a sufficient fixed fibrous layer. At present autologous tissue should be taken for obliteration. It should be easy and rapidly to take, harvesting should not cause any or significant donor-site morbidity, and follow-up with CT and MR should not be hindered.

- Although adipose tissue transplantation does not fulfil all these criteria it has proven its effectiveness since decades and represents the best compromise at present. To minimise donor-site morbidity haemostasis should be performed meticulously and a suction drain should be placed.
- Spontaneous obliteration including filling up the cavity with blood with peri-operative antibiotic therapy or
- use of fibrous tissue (e.g. galeaperiosteum) seem to be alternatives thinking of operation technique, morbidity, costs and follow-up. These two methods should be considered particularly in small frontal sinuses and when the orbital roof is intact.
- Use of the temporalis muscle can be taken into account as alternative method too, but causes some pain in mastication and occasionally visible swelling of the temporal region. In very rare cases retraction of the orbital content may occur and lead to cosmetic and functional disturbances. One well documented case of the literature occurred 6 months after osteoplastic flap procedure with fat obliteration and caused enopthalmos and upper eye lid retraction (Shore et al. 1987). This is probably independent of the material if there is any potential of fibrous replacement, but it seems to be very rare. In our experience of more than 100 operations there was no such complication.
- Bony materials or osteoinductive and osteoconductive materials seem to have disadvantages which do not favour them as method of first choice: there may be some risk to put in too much bone with compression of the orbit in case of missing walls. There may be further problems if a mucocele forms posteriorly which will develop towards the orbit and brain and is much more difficult to operate because of the thick bone mass in front of it. Nevertheless, transplantation of bony materials like bank bone may be the treatment of choice in combining obliteration of the frontal sinus and reconstruction of the forehead.

Prospective and long-term examinations using MR imaging and nasal endoscopy have to answer the question to which extent post-operative infections, mucoceles and (minor) ingrowth of mucosa will occur using the alternative operation techniques. Postoperative MR imaging is therefore an essential part of a successful comprehensive therapeutic concept. It precisely allows documentation of recurrent disease and outcome analysis. New materials for frontal sinus obliteration have to be compared with the above listed requirements and should offer well defined advantages before any use could be recommended.

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