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MAIN ARTICLE

Collagen matrix as an inlay in endoscopic skull base reconstruction

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Abstract

Background: Multi-layer reconstruction has become standard in endoscopic skull base surgery. The inlay component used can vary among autografts, allografts, xenografts and synthetics, primarily based on surgeon preference. The short- and long-term outcomes of collagen matrix in skull base reconstruction are described.

Methods: A case series of patients who underwent endoscopic skull base reconstruction with collagen matrix inlay were assessed. Immediate peri-operative outcomes (cerebrospinal fluid leak, meningitis, ventriculitis, intracranial bleeding, epistaxis, seizures) and delayed complications (delayed healing, meningoencephalocele, prolapse of reconstruction, delayed cerebrospinal fluid leak, ascending meningitis) were examined.

Results: Of 120 patients (51.0 ± 17.5 years, 41.7 per cent female), peri-operative complications totalled 12.7 per cent (cerebrospinal fluid leak, 3.3 per cent; meningitis, 3.3 per cent; other intracranial infections, 2.5 per cent; intracranial bleeding, 1.7 per cent; epistaxis, 1.7 per cent; and seizures, 0 per cent). Delayed complications did not occur in any patients.

Conclusion: Collagen matrix is an effective inlay material. It provides robust long-term separation between sinus and cranial cavities, and avoids donor site morbidity, but carries additional cost.

Key words: Endoscopic Surgery; Skull Base; Collagen

Introduction

The increasing use of endoscopic approaches for tumour resection is associated with potential donor morbidity for autologous tissue used in skull base reconstruction. Ensuring post-operative separation between the intracranial and sinonasal cavities is important, not only to avoid cerebrospinal fluid (CSF) leak, but also in preventing future meningitis, ventriculitis and intracranial abscess.[1] A number of materials have been utilised in a variety of combinations and layers for skull base reconstruction, often based on surgeon preference or local experience.

Materials most commonly used in the reconstruction layers are: inlay grafts, including autologous fat,[2–6] fascia,[2,7–10] bone[11,12] and cartilage;[12] engineered allografts (i.e. acellular dermal matrix[12–15]); and synthetic materials (porous polyethylene plate,[16] hydroxyapatite cement[17]). These layers are frequently followed by the application of mucosal or vascularised grafts, fibrin sealants, and absorbable and/or non-absorbable packing.[1,18] Overall, successful repair of skull base defects has been reported in the literature to be over 90 per cent, regardless of the materials or technique used.[19]

The use of vascularised overlay grafts can lead to improved outcomes compared to free mucosal grafts in the case of larger defects or high-flow CSF leaks.[18,20] With respect to inlay grafts, however, it is unclear if any material is superior to another in achieving successful repair. Fat and fascia autografts are frequently used, but are associated with donor site morbidity. Allografts and xenografts that have established utility in skull base surgery include acellular dermal matrix (AlloDerm; LifeCell, Branchburg, New Jersey, USA),[12–15,21,22] porcine small intestine (BioDesign®)[23] and collagen matrix products,[24–26] but these carry additional costs.

Although commonly utilised, the literature on collagen matrix in endoscopic endonasal skull base surgery

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is limited. We describe the short- and long-term outcomes of a collagen matrix used as a dural inlay, with a single mucosal graft layer, in endoscopic skull base reconstruction.

Materials and methods

A retrospective case series was performed of consecutive patients from a tertiary rhinology practice who underwent endoscopic skull base reconstruction using DuraGen collagen matrix (Integra Neurosciences, Plainsboro, New Jersey, USA) as an inlay graft.

Data collected from the patient population included age, gender, smoking status, history of chronic rhinosinusitis, asthma, post-operative radiation therapy, benign or malignant pathology, and origin of pathology. Smokers were defined as any patient currently smoking or who had ceased within the last 12 months. Chronic rhinosinusitis was defined as per the European Position Paper on Rhinosinusitis and Nasal Polyps ('EPOS') guidelines, with both symptoms and evidence of non-tumour related sinus inflammation on endoscopy (with or without computed tomography evidence).[27] Asthma status was determined by a positive spirometry result on challenge testing or β-agonist use, or if currently using regular inhaled bronchodilator or corticosteroid therapy. Although all surgery was transdural, the origin of pathology was defined as either intracranial or paranasal sinus in origin.

All patients had collagen matrix as the first layer of their skull base reconstruction, placed intracranially as an inlay graft in the subdural or arachnoid space (Figure 1). This was followed by a free mucosal graft (usually for defects less than 1 cm), a vascularised mucoperiosteal flap or a combination. Porcine gelatine sponge was used to cover the reconstruction, and a bolster of either absorbable (NasoPore; Polyganics, Groningen, Netherlands) or removable packing (Bismuth iodine paraffin embedded gauze or Foley balloon) was used to keep the repair in place.

A standard post-operative management protocol was followed, which consisted of at least 1 night in the intensive care unit, with bed rest for 48 hours, then mobilisation. Intravenous antibiotics were administered while the patient was in hospital, followed by 10 days of oral antibiotics and twice daily saline irrigations upon discharge.

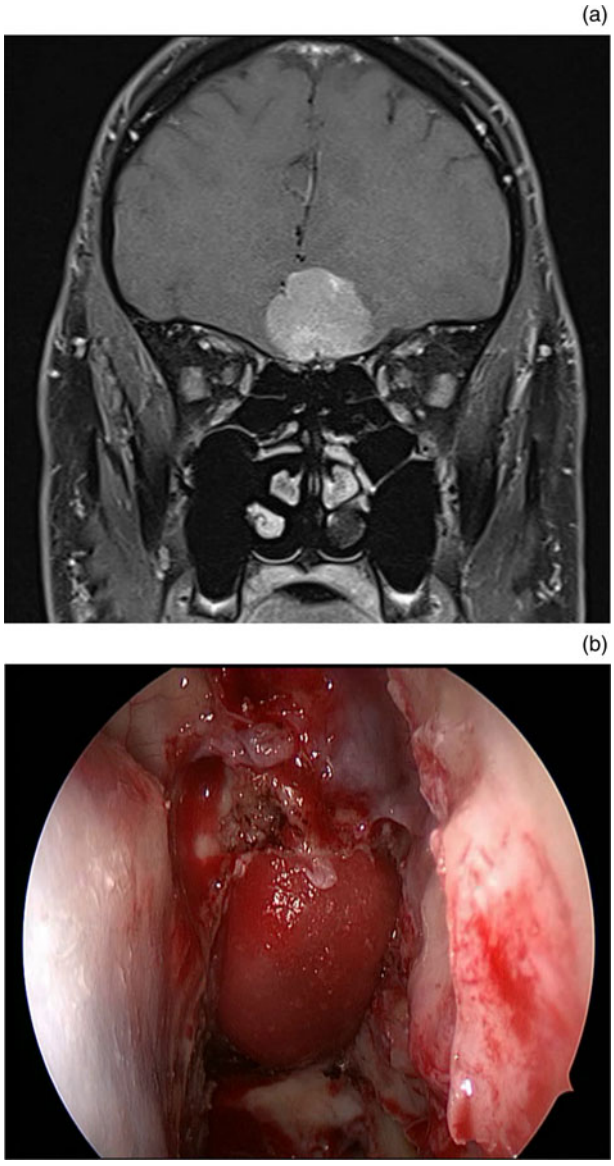


FIG. 1

(a) Pre-operative, coronal, T1-weighted, post-contrast fat-saturation magnetic resonance imaging scan of a left olfactory groove meningioma in a 43-year-old male. (b) Intra-operative view of the collagen matrix inlay as the first layer of the skull base reconstruction following resection of this tumour. This was followed by a nasoseptal flap overlay.

Peri-operative morbidity

Immediate peri-operative outcomes (occurring three months or less post-operatively) were assessed, including CSF leak, meningitis, other intracranial infections (ventriculitis or cerebritis), intracranial bleeding, epistaxis and seizures. The diagnosis of CSF leak was based on surgeon assessment according to clinical evidence of CSF leaking from the surgical site. Any CSF leaks that occurred within days of the surgery did not require confirmation with a β−2 transferrin test and were treated with re-operation. Meningitis was diagnosed for any patient with positive CSF cultures or clinical symptoms consistent with the diagnosis, such as fever, headache, neck stiffness, photophobia and leukocytosis. Diagnosis of ventriculitis was based on clinical symptoms, magnetic resonance imaging findings and positive CSF cultures. Intracranial bleeding consisted of any collection of blood under the skull base repair, or otherwise in the epidural, subdural or intraventricular space, which necessitated medical or surgical intervention to manage, such as a return to the operating theatre for evacuation or medical treatment of intracranial pressures. Epistaxis was defined as persistent, brisk bleeding from the nose that required nasal packing, electrocautery or other surgeon intervention

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to manage. Seizure diagnosis was based on witnessed seizure activity meeting clinical criteria.

Delayed complications

In addition, delayed complications (occurring more than three months post-operatively) were examined, which included delayed healing, meningoencephalocele formation, prolapse of reconstruction, delayed CSF leak and ascending meningitis. Delayed healing consisted of any ongoing sinus dysfunction, in the form of persistent epithelial disruption, ulceration, granulation tissue, serous weeping or bleeding, abnormal crusting, or dehiscence of the vascularised flap–sinus mucosal margin. Meningoencephalocele was defined as protrusion of meningeal and brain tissue into the paranasal sinus cavity. Prolapse of reconstruction involved the extension of both the reconstructive layers and the adjacent underlying intracranial contents beyond the bony margin of the skull base, with or without dislodgment of the reconstruction. Delayed CSF leak and ascending meningitis were diagnosed as described above, but occurred outside the three-month post-operative timeframe.

Statistical analysis

Statistical assessment was performed using SPSS version 22 software (IBM, Armonk, New York, USA). Descriptive data are presented as percentages and means ± standard deviations (SDs) for parametric data and medians (interquartile ranges) for non-parametric data. The chi-square test and Fisher's exact test were used for the analysis of nominal values. The student's *t*-test (two-tailed) was employed for the comparison of parametric data. Results with a p value of less than 0.05 were considered significant.

Results

A total of 120 patients (mean age of 51.0 ± 17.5 years, 41.7 per cent female), presenting from October 2008 to September 2015, were assessed. Of these, 4.7 per cent were smokers and 11.4 per cent had a pre-operative diagnosis of asthma. A total of 28.3 per cent of skull base reconstructions were the result of malignant pathology and 53.3 per cent of all pathology was of intracranial origin. Post-operative radiation therapy was necessary in 28.7 per cent of patients. Average follow-up duration was 39.0 months (range, 23.0–58.8 months).

Following placement of the collagen matrix inlay, a nasoseptal flap was used as an overlay graft in 69.2 per cent of cases. Patients with pathology of intracranial origin were statistically more likely to receive a nasoseptal flap (62.7 *vs* 32.4 per cent, $p < 0.05$). There were otherwise no differences between the patients receiving nasoseptal flaps versus those with non-vascularised repairs (Table I).

There was an all-inclusive peri-operative complication rate of 12.7 per cent, in which one complication occurred in 10.8 per cent of patients ($n = 13$) and two complications (CSF leak and other intracranial infection) occurred in 0.8 per cent of patients ($n = 1$). Of these complications, 3.3 per cent were CSF leaks, 3.3 per cent were meningitis, 2.5 per cent were other intracranial infections, 1.7 per cent were intracranial bleeding and 1.7 per cent were epistaxis. There were no peri-operative seizures. Delayed complications (delayed healing, meningoencephalocele, prolapse of reconstruction, delayed CSF leak and ascending meningitis) did not occur in any patients.

TABLE I
BASELINE DEMOGRAPHIC AND TREATMENT FACTORS*

Factor	Reconstruction type		p
	Nasoseptal flap†	Non-vascularised‡	
Age (mean ± SD; years)	50.7 ± 16.8	51.9 ± 19.1	0.73
Gender (% female)	45.8	32.4	0.23
Smokers (%)	5.4	3.0	1.0
Asthmatics (%)	10.4	14.3	0.73
Allergy (%)	42.5	35.3	0.77
Chronic rhinosinusitis (%)	3.9	7.1	0.61
Radiotherapy (%)	32.1	20.0	0.25
Pathology (% malignant)	26.5	32.4	0.52
Location (% intracranial)	62.7	32.4	0.003

*Comparison between patients with nasoseptal flap based reconstruction versus those without. †$n = 83$; ‡$n = 37$. SD = standard deviation

Factors associated with complications

There was no significant difference between patients who had a CSF leak and those who did not with respect to age (58.5 ± 11.9 *vs* 50.8 ± 17.6 years, $p = 0.39$), gender (50.0 *vs* 41.4 per cent female, $p = 1.0$), smoking (0.0 *vs* 4.9 per cent, $p = 1.0$), asthma (50.0 *vs* 9.9 per cent, $p = 0.06$), chronic rhinosinusitis (0.0 *vs* 5.0 per cent, $p = 1.0$), radiation therapy (33.3 *vs* 28.6 per cent, $p = 1.0$), tumour character (25.0 *vs* 28.4 per cent malignant, $p = 1.0$), tumour origin (75.0 *vs* 52.6 per cent intracranial, $p = 0.62$) or use of a nasoseptal flap (50.0 *vs* 69.8 per cent, $p = 0.59$) after collagen matrix inlay. Whether or not a nasoseptal flap was used following collagen matrix inlay had no effect on the rate of any of the peri-operative complications (Table II).

Discussion

Collagen matrix is effective as an inlay graft in endoscopic skull base reconstruction. Collagen has been assessed in skull base reconstruction in the open repair of middle cranial fossa[24,26] and posterior cranial fossa defects,[25] with similar peri-operative outcomes as those in this study. When it comes to graft materials selected and number of layers used, no reconstructive strategy appears to be superior to others. Comparative studies are uncommon and most publications are retrospective case series, with heterogeneity of reconstructive methods. There is heterogeneity in terms of patient characteristics, graft material, number of

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TABLE II
COMPARISON OF COMPLICATION RATES FOR NASOSEPTAL FLAP VERSUS NON-VASCULARISED REPAIR GROUPS*

Complication	Type of reconstruction		*p*
	Nasoseptal flap†	Non-vascularised‡	
Peri-operative morbidity (%)			
– CSF leak	2.4	5.4	0.59
– Meningitis	4.8	0.0	0.31
– Other intracranial infective	2.4	2.7	1.0
– Intracranial bleed	2.4	0	1.0
– Epistaxis	2.4	0	1.0
– Seizure	0	0	–
Delayed morbidity (%)			
– Meningoencephalocele	0	0	–
– Reconstruction prolapse or shifting	0	0	–
– Delayed >3 months	0	0	–
– Delayed CSF leak	0	0	–
– Ascending meningitis	0	0	–

*Comparison based on whether or not a nasoseptal flap was used as part of skull base reconstruction following placement of collagen matrix layer. †$n = 83$; ‡$n = 37$. CSF = cerebrospinal fluid

layers used, overlay graft selection and peri-operative management employed. A structured summary of the various underlay materials described in the literature for endoscopic skull base reconstructions in the last 10 years is presented in Table III.[2–17,23,28–33]

Autologous tissue is an established underlay material. Common autografts include abdominal or thigh fat, fascia, cartilage, and bone. Fat has proven useful in obliterating dead space, whether intracranially or in the sphenoid sinus. Fascia lata also can be used successfully either as an individual underlay or in multiple layer fashion.[8] Both of these autologous materials have the benefit of being readily available on a patient, with no risk of foreign body reaction or disease transmission. However, they both require a separate donor site, which carries with it potential morbidity, such as infection, haematoma, seroma, cosmetic concerns and possibly increased operative time for harvest. Abdominal haematoma has been reported to occur in 0.9–3.2 per cent of cases.[6,34] For autologous fat, a 1 per cent complication rate, in a series of 974 patients who underwent skull base reconstruction, has been reported.[35] These complications included leakage of liquefied fat from a fistula, delayed CSF leak after radiation, and lipoid meningitis. Two cases of lipoid meningitis were also reported in a series in which fat graft was used for translabyrinthine craniotomies, requiring CSF diversion.[36]

Autologous cartilage or bone are often utilised to provide a rigid buttress to the repair. One method that has been described is the 'gasket seal' method, in which fascia lata is placed in the defect followed by a bony buttress, which is then countersunk, wedging its edges beyond the bony defect edges, holding it firmly in place.[37] Although it has proven effective, whether or not this type of rigid support is needed is not known. This study's authors have removed bone and titanium sequestra from skull base reconstructions performed elsewhere at three months and beyond. Such a repair introduces the potential for sequestra formation; furthermore, it still needs to be combined with another soft tissue material, and is of questionable additional benefit when vascularised mucosal graft already improves the outcome for large dural defects and high-flow CSF leaks.[18,20] These rigid autologous grafts can be taken from resected sinonasal tissue that would otherwise be discarded, such as the septum or turbinates, making them convenient options. However, their availability is dependent on involvement in the primary pathology. Therefore, they are not a consistent or reliable option in skull base reconstructions. Rigid and non-rigid allografts and synthetic materials, on the other hand, are readily available materials that can be customised to a given defect intraoperatively, but these risk rejection under a thin mucosal surface.

DuraGen is a collagen-based dural replacement product that is derived from freeze-dried ground bovine Achilles tendon. This collagen foam is processed to remove any cellular or immunogenic components, and chemically crosslinked, giving it its porosity and matrix structure. In a canine model, Zerris *et al.* compared the physico-mechanical properties, structure and performance of DuraGen and two other available collagen-based dural replacement products, Dura-Guard (Synovis, Saint Paul, Minnesota, USA), derived from bovine pericardium, and Durepair (TEI Biosciences, Boston, Massachusetts, USA), derived from fetal bovine dermis. DuraGen was demonstrated to be a much more delicate material than Durepair or Dura-Guard, have a larger pore size (100 μm in DuraGen, *vs* 10–20 μm in Durepair and 5 μm in Dura-Guard), and be much more quickly incorporated into and replaced by native host tissue (four weeks *vs* six months).[38] In endoscopic CSF leak repair, remucosalisation time was shown to occur significantly sooner

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TABLE III
SUMMARY OF UNDERLAY MATERIALS DESCRIBED FOR ENDOSCOPIC SKULL BASE RECONSTRUCTIONS IN LAST 10 YEARS

Reconstruction type & material	Study	Year	Cases (*n*)	Mean follow up (mths)	Product	Intracranial	Extracranial	Mucosa graft	CSF leak (%)	Infection (%)	Revision (%)	Notes
Non-rigid												
Autologous												
– Fat												
	Sanders-Taylor *et al.*[6]	2015	235	18.5	Fat	Fat, septal bone or cartilage	Biological glue, Nasopore	None	1.7	0.85	0.43	
	Bhavana *et al.*[3]	2014	5	12.0	Fat	Fat autograft (bath-plug technique) ± septal cartilage (40%)	Fascia lata, fibrin glue	None	0.0	0	0	
	Kong *et al.*[5]	2011	58	16.5	Fat	Fat	Mucosa graft	Free graft	5.2	6.9	10.3	
	Farooq *et al.*[4]	2011	22	DNS	Fat	Fat	Mucosa graft (30.4%)	Mucosa graft (30.4%)	4.3	0.0	4.3	
	Bernal-Sprekelsen *et al.*[2]	2014	54	15.6	Fat + lyophilised fascia lata	Fat + lyophilised fascia lata	Nasoseptal flap, Surgicel ± fibrin glue, finger cot pack	Vascularised	0.0	9.0	0.0	
– Fascia lata												
	Eloy *et al.*[13]	2013	10	7.4	Fascia lata, AlloDerm	Fascia lata, AlloDerm	Nasoseptal flap, Gelfoam, Merocel	Vascularised	0	0	0	
	Luginbuhl *et al.*[8]	2010	20	DNS	Fascia lata	Fascia lata	Nasoseptal flap, Nasopore, fibrin glue	Vascularised	10	DNS	15	High-flow or open cistern leaks
	Chatrath *et al.*[28]	2006	3	5	Temporalis fascia, bone pate (from mastoid cortex)	Temporalis fascia	Bone pate + fibrin glue, mucosa graft, fibrin glue, Gelfoam	Free graft	0	0	0	
	Bernal-Sprekelsen *et al.*[2]	2014	62	75.3	Lyophilised fascia lata	Lyophilised fascia lata	Free mucosa graft, Surgicel, finger cot pack	Free graft	1.6	1.6	1.6	
	Villaret *et al.*[10]	2010	62	17.5	Fascia lata	Fascia lata × 3 layers (small pieces of fat between layers)	Silastic, finger cot packs	None	13.0	1.5	4.8	
	Amit *et al.*[7]	2013	25	12	Fascia lata	Fascia lata	2nd layer of fascia lata, nasoseptal flap (80%), Surgicel, fibrin glue, Gelfoam, non-absorbable packing	Vascularised (80%), none (20%)	4.0		4.0	
	Ozturk *et al.*[9]	2012	12	21	Fascia lata	Fascia lata	Fat for sphenoid obliteration, fibrin glue (50%), Nasopore, Merocel	None	16.7	8.3	33.3*	2 patients had 2 revisions (3 total surgical procedures each)
Non-autologous												
– Collagen (DuraGen, DuraMatrix, Durepair)												
	Zanation *et al.*[29]	2011	28	DNS	Collagen matrix	Collagen matrix	Nasoseptal flap, Surgicel, DuraSeal, Gelfoam, Foley balloon or sponge	Vascularised	5.0	0	5.0	
	Hadad *et al.*[30]	2006	43	>2	Collagen matrix	Collagen matrix + 2nd layer collagen matrix or fat graft	Nasoseptal flap, fibrin glue, non-absorbable packing or Foley balloon	Vascularised	4.7	0	4.7	
– Dermal (AlloDerm)												

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	Gaynor *et al.*[14]	2013	95	DNS	AlloDerm	AlloDerm (1 mm, pie-crust closure)	Surgicel wrapped Gelfoam, ± additional AlloDerm layer, Gelfoam, Merocel packing in sphenoid	None	8.4	DNS	0.9 overall (half from AlloDerm group)	Pituitary patients with intra-operative CSF leaks
	Germani *et al.*[12]	2007	30	7.6	AlloDerm	AlloDerm (alone 40%) ± bone (6.6%) or cartilage (3.3%)	Gelfoam, Merocel packing	Free graft (50%), none (50%)	3.3	0	3.3	
	Ismail *et al.*[15]	2007	21	16	AlloDerm	AlloDerm	Fibrin glue, 2nd AlloDerm layer, fat graft to obliterate sinus, fibrin glue, Gelfoam, Merocel packing	None	9.5	0	9.5	
	Eloy *et al.*[13]	2013	10	7.4	Fascia lata, AlloDerm	Fascia lata, AlloDerm	Nasoseptal flap, Gelfoam, Merocel	Vascularised	0	0	0	
– Other												
	Cavallo *et al.*[31]	2007	21	DNS	Tutoplast, Lactosorb	Dehydrated human pericardium, Lactosorb (copolymer of L-lactic acid & glycolic acid) bone substitute	2nd layer of pericardium (76.2%), nasoseptal flap (14.3%), Surgicel, fibrin glue &/or BioGlue (semisynthetic bovine sealant), Foley balloon (76.2%)	None (85.7%), nasoseptal flap (14.3%)	9.5	0 meningitis (4.8 mycotic sinusitis)	9.5	
– Porcine intestine												
	Illing *et al.*[23]	2013	155	19.3	Porcine small intestine submucosa graft	Porcine small intestine submucosa graft (78.8%)	Porcine small intestine submucosa graft (88.8%), Nasoseptal flap, Evicel, Gelfoam, Merocel	Vascularised	5.8	0.6	5.8	Infection rate = 1.9% if include cases of invasive fungal sinusitis & peri-orbital cellulitis
Rigid												
Autologous												
– Bone or cartilage												
	Emanuelli *et al.*[11]	2015	10	38	Bone	Fascia lata (55%) or heterologous biological material (10%), middle turbinate bone (95%)	Mucosa-free graft, fibrin glue, non-absorbable packing	Free graft	0.0	0.0	0.0	
	Germani *et al.*[12]	2007	13*	7.6	Bone	Bone (11/13) or cartilage (3/13), AlloDerm (3/13) or bone paste (1/13)	Mucosal graft (10/13), Gelfoam, Merocel pack	Free graft	15.4	0.0	7.7	CSF leaks were 1 bone paste, 1 bone + mucosal graft
	Chung *et al.*[17]	2012	39*	8.6	Bone	Fascia lata, fibrin sealant, autologous bone (73.6%), hydroxyapatite cement	None	None	5.6	5.6	5.6	54 in total group, CSF leaks for patients with bone layer not specified
Non-autologous												
– Medpor												

Continued

Table III *Continued*

Reconstruction type & material	Study	Year	Cases (*n*)	Mean follow up (mths)	Product	Intracranial	Extracranial	Mucosa graft	CSF leak (%)	Infection (%)	Revision (%)	Notes
– Other	Wessell *et al.*[32]	2013	5	10	Rectus fascia + Medpor plate (modified gasket seal technique)	Rectus fascia + Medpor plate (modified gasket seal technique)	Nasoseptal flap, fibrin glue	Vascularised	0	40 (aseptic meningitis)	0	Also, 2/5 (40%) had new 'chronic/ recurrent sinusitis post-operatively'
	Kong *et al.*[5]	2011	46	16.5	Fascia lata + cadaveric iliac bone	Fascia lata + cadaveric iliac bone (gasket seal technique)	2nd layer of fascia lata, Gelfoam or collagen sponges, DuraSeal	None	4.3	8.7	4.3	
	Tabaee *et al.*[33]	2013	4	>3	Bioabsorbable mini-plate	Fat, fascia or AlloDerm, bioabsorbable mini-plate	Tissue sealant, Gelfoam, non-absorbable packing	None	25.0	0.0	0.0	
	Chung *et al.*[17]	2012	53	8.6	Hydroxyapatite cement	Fascia lata, fibrin sealant, autologous bone (73.6%), hydroxyapatite cement	None	None	5.6	5.6	5.6	

FIG. 2

(a) Coronal, T1-weighted, post-contrast fat-saturation magnetic resonance imaging (MRI) scan of a patient at post-operative day 1 following resection of sinonasal squamous cell carcinoma with collagen matrix underlay as part of the skull base reconstruction. The hypointensity of this underlay (thick arrow) can be observed in the anterior cranial fossa abutting the brain, under which the enhancing nasoseptal flap overlay is seen (thin arrow), followed by absorbable packing and a Foley catheter balloon in the nasal cavity. (b) This same reconstruction observed on a T2-weighted, fat-saturation MRI scan.

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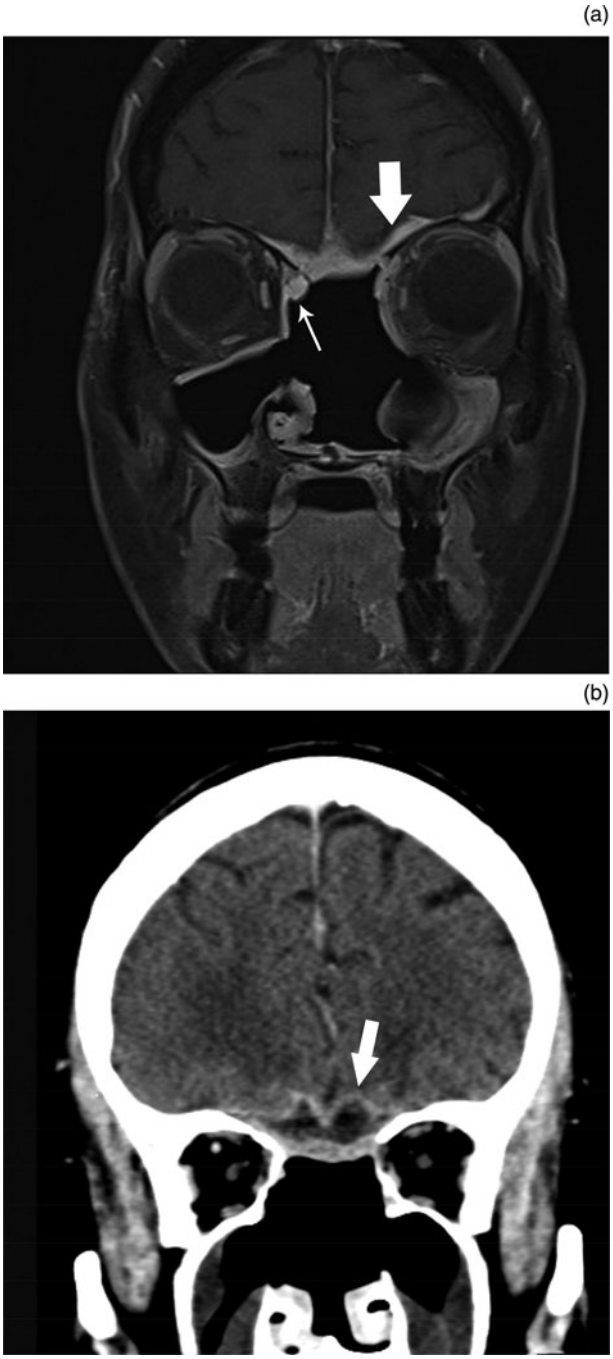


FIG. 3

(a) Coronal, T1-weighted, post-contrast fat-saturation magnetic resonance imaging scan of the same patient as in Figure 2, five weeks following squamous cell carcinoma resection. Note the enhancement of the collagen matrix underlay (thick arrow), which could be easily confused with meningeal enhancement from extension of the malignancy. The pedicle of the nasoseptal flap overlay can also be observed (thin arrow). (b) Coronal computed tomography brain scan, with contrast, of a patient six weeks following endoscopic resection of an anterior cranial fossa meningioma, showing hypodensity of the collagen matrix underlay (arrow), which could be mistaken for a fluid collection on imaging.

with collagen matrix products (DuraGen and DuraForm) compared to acellular dermal matrix (AlloDerm) (6.6 *vs* 11.7 weeks), but second to mucosal grafts (4.9 weeks).[39] No significant foreign body reaction was noted for any of the bovine collagen grafts.[38] Figure 2 demonstrates early post-operative imaging characteristics of collagen matrix underlay. Radiologists need to be aware of the expected appearance of this reconstructive layer to avoid confusion with residual or recurrent disease or signs of an infective process (Figure 3), an error that has occurred in the past.[40]

Acellular dermal matrix (AlloDerm) is a commonly used allograft made from cadaveric human skin that has been specially treated to remove all cellular and immunogenic components. Gaynor *et al*. compared transsphenoidal pituitary surgery reconstructions using acellular dermal matrix and fat graft in the event of intra-operative CSF leak, and found equivalent success between them.[14] There were 160 cases of intra-operative CSF leak, with 8.4 per cent in the acellular dermal matrix group versus 15.2 per cent in the fat graft group with reported post-operative leak ($p = 0.34$). Several other studies have reported over 90 per cent success rate of skull base reconstruction with the use of acellular dermal matrix.[12,15,21,22,41]

- **Ensuring post-operative separation between the intracranial and sinonasal cavities is important to prevent significant morbidity**
- **There are various inlay graft materials for endoscopic skull base reconstruction available to the surgeon**
- **These include autologous fat, fascia, bone, cartilage, engineered allografts and synthetic materials**
- **Collagen matrix is an effective inlay graft; it provides a robust endoscopic skull base repair, is easily obtainable and avoids donor site morbidity**

Collagen matrix presents similar advantages to acellular dermal matrix, in that there is no donor site morbidity, it is readily available and it can be sized to the defect. With either allografts or xenografts, there is a theoretical risk of transmissible spongiform encephalopathies, such as Creutzfeldt–Jakob disease. However, the World Health Organization have designated these substances as not having any detectable infectivity; they are processed to eliminate any potential infectivity, and there have been no reports of disease transmission in more than two million uses.[38,42,43]

This study has the advantages of a large study population, a long follow-up time, and a variety of sinonasal and skull base pathology and subsequent skull base defects. Nevertheless, it remains limited by its retrospective nature and an inability to compare to other reconstructive methods.

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Conclusion

Various reconstruction strategies are available. Collagen matrix, in a simple two-layer reconstruction, is an effective option for endoscopic skull base repair. It is readily obtainable and without donor site morbidity. It provides a robust reconstruction that prevents ascending infection and delayed breakdown, and it is rigid enough to withstand intracranial pressure forces. While it carries additional cost, this is weighed against the surgical consumables used to harvest, repair and dress the donor site.

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