Advances in vascularized flaps for skull base reconstruction

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Purpose of review
Advances in anterior skull base surgery have resulted in the increasing diversification of reconstructive techniques. New vascularized flaps have been suggested in the last years, some quite similar, whereas new uses and applications have been suggested for some vascularized flaps, which have already established their value over the last decades. In this article, we describe the developments in skull base reconstruction with vascularized flaps and analyse the international experience in the use of vascularized flaps published with a focus on the last 18 months.

Recent findings
Over the past 18 months, a number of novel or modified vascularized intranasal flaps have been described, focusing on reconstruction of larger defects, the medial orbital wall, the anterior skull base (septal flip-flap) and dissection of the nasoseptal flap from the SPA foramen. Extranasal vascularized flaps, which have been around for a long time, still have their rightful place in skull base reconstruction and have recently been adjusted for endoscopic use.

Summary
We present an overview of the latest developments in vascularized flaps (intranasal and extranasal), their new implications, their modifications and complications or predictions of viability.

Keywords
cerebrospinal fluid leaks, microvascular reconstruction, skull base defects, skull base reconstruction, vascularized flaps

INTRODUCTION

Simple transphenoidal endonasal approaches for hypophyseal tumours not extending above the diaphragm sellae, during which the arachnoid is not breached, are associated with a low incidence of cerebrospinal fluid (CSF) leaks and do not routinely require extensive reconstruction. However, extended endoscopic endonasal skull base surgery entails large dural defects, frequently communicating directly with areas of high flow, such as the third ventricle. Reconstruction of such large dural defects following extended endonasal approaches (EEA) has been, and remains, a major challenge [1]. This was indeed the major limiting factor in the early days of EEAs – with rates of CSF leaks reported as high as 65% [2] Several techniques have been suggested to deal with this problem, including a variety of grafts both autologous, heterologous or artificial, as well as flaps, including vascularized free and pedicled flaps.

Vascularized pedicled flaps yield superior outcomes when compared with free tissue grafts as vascularized flaps promote faster and more complete healing by restoring local blood flow, as exemplified by the Hadad-Bassagasteguy flap or nasoseptal flap (NSF) [3]. Following the NSF, many different/modified intranasal vascularized flaps tailored for specific disorders have been described [4], including a very recently described flap, the septal flip-flap [5▪▪].

Prior to the era of extended endonasal approaches, open skull base techniques included a variety of methods to repair skull base dural defects and prevent CSF leaks. Some of these techniques have been adapted for endoscopic surgery, like the endoscopic-assisted pericranial flap [6], whereas

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Curr Opin Otolaryngol Head Neck Surg 2021, 29:36–43
DOI:10.1097/MOO.0000000000000690

KEY POINTS

- In order for an intranasal vascularized flap to reach more anteriorly either the nasal flip-flap can be useful or the NSF can be released from the SPA foramen and left attached to the internal maxillary artery.
- Tailoring the harvest of intranasal flaps to the anatomy and size of defect helps reduce minor complications, such as postoperative crusting, and the use of silicone strips reduces synechia formation.
- When defects in the skull base are too large or too distant for intranasal flaps alone or when the patient has received extensive radiation, extranasal vascularized flaps with or without intranasal flaps form a viable option.
- In the case of high-flow clival defects, initially vascularized intranasal flaps and if not available, a temporoparietal flap or otherwise a pericranial flap (third option) should be used.
- Younger paediatric patients differ by having a variable pneumatization, small nasal cavities, limited capacity for blood loss and the nasal septal flap (with or without additional flaps) can be used successfully for skull base reconstruction.

another extranasal flap used extensively in head and neck reconstruction is the *temporoparietal flap,* which has been adapted for endoscopic surgery [7].

Paediatric patients, particularly those $\leq$6 years of age, present a unique set of challenges for the skull base surgeon. These may include variable pneumatization, small nasal cavities, limited capacity for blood loss because of smaller total blood volume and postsurgical developmental concerns [8▪]. That is why we will discuss separately the vascularized flaps used in this patient group.

Review

Following the initial description of the NSF, many modified intranasal vascularized flaps were subsequently developed for use in specific disorders, whereas extranasal vascularized flaps used in head and neck reconstruction or open skull base techniques have been adjusted for endoscopic surgery.

Intranasal flaps

Current options for vascularized endonasal flaps include the NSF (pedicled on nasoseptal artery), the posterior pedicled inferior turbinate flap [9] (ITF, pedicled on the inferior turbinate artery, a branch of the posterolateral nasal artery) and middle or anterior inferior turbinate flap.

The superior turbinate flap is rarely used. Both superior turbinates are very often sacrificed during surgery while performing a standard posterior septectomy and sphenoidotomy. Recently a single-centre experience has been published [10] on the use of the superior turbinate flap in sellar defects (with low, middle or high flow) concluding that the superior turbinate flap can be used for the vascularized reconstruction of sellar defects if it is bilaterally available, taking into account the anatomical variations of the superior turbinates.

A standard NSF is described for marsupialization of rathke cleft cyst. The concept is that, in order to promote long-term drainage and re-epithelialization of the rathke cleft cyst, the floor of the cavity is lined with NSF, which is rotated over the sphenoid floor and clivus, thus providing coverage of the exposed bone and adding an additional 'stenting' effect [11▪]. This results in the creation of an infrasellar drainage pathway and a gravitationally directed trajectory for cyst contents. In their patient cohort ($n = 7$), the authors report that they achieved an open drainage for the cyst, good healing because of re-epithelialization and improved postsurgical outcomes. Similar use of the NSF has been described in order to keep the drainage of a cholesterol granuloma of the petrous apex [12] A recent case of ours presented with multiple cranial neuropathy because of a recurrent cholesterol granuloma of the petrous bone. The patient was operated with an endoscopic transnasal approach and after drainage, the floor of the cavity and clivus was lined with NSF. A year later, the drainage pathway was patent (Fig. 1a), without evidence of recurrence.

In order to cover a large defect, a new one-piece combined inferior turbinate-NSF (IT-NSF) was described [13]. It is essentially a modification of the original NSF and includes in addition to the mucosa of the nasal septum, the mucosa of the inferior turbinate, the inferior meatus and the nasal floor with conservation of both vascular pedicles coming from the posterior septal and lateral nasal artery of the inferior turbinate. (Fig. 2).

Another technique to cover large defects is the septal flip-flap [14]. This pedicled flap is based on the septal branches of the contralateral ethmoidal arteries (Fig. 3) and is harvested using the contralateral mucoperiosteum and mucoperichondrium of the nasal septum. Although it requires the removal of the superior part of the nasal septum, it might give an additional value in its greater coverage of the anterior portion of an anterior skull base defect. Recently, the same research group published their long-term outcomes of using this flap [5▪▪]. Defect sizes ranged from 2 to 6 cm^2 and all patients were treated with either neo or adjuvant radiotherapy.

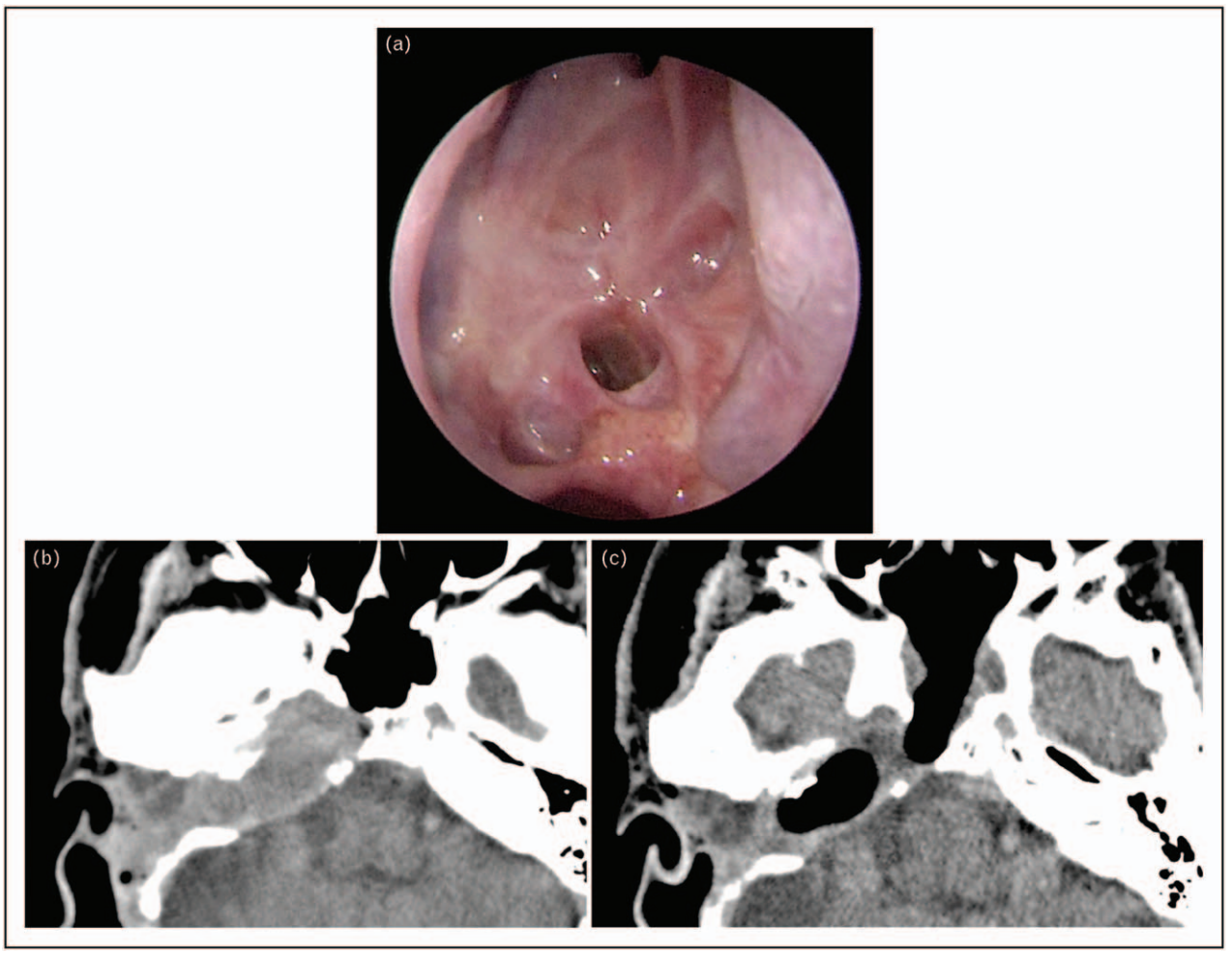

FIGURE 1. (a) Postoperative endoscopic image showing a well healed cavity with an open drainage. (b) Preoperative CT scan showing a cholesterol granuloma in de right petrous bone. (c) Postoperative CT scan showing an open cavity with drainage of the cholesterol granuloma. CT, computed tomography,.

Successful skull base reconstruction was obtained in 96% of the patients (23 out of 24 patients).

Another modification of the NSF was described for the simultaneous reconstruction of skull base and medial orbital wall defects [15]. A difference to the standard NSF is that the standard incision along the anterior septum is extended superiorly into the nasal vault and then along the lateral nasal wall, ending just superior to the head of the inferior turbinate. The mucosa is incised along the roof of the nasal cavity at the attachment of the middle turbinate and transitions to a superior septal incision that is then developed posteriorly along the face of the sphenoid. The final incision is made along the inferior meatus and posterior nasal floor allows the mucosa of the entire ipsilateral septum and anterior nasal floor to be included (Fig. 4). The flap is rotated in a manner such that the nasal floor mucosa is covering the medial orbit, and the lateral nasal wall mucosa is included in flap closure of the skull base defect. For oncologic reasons, the flap is raised on the side contralateral to tumour.

Finally, in an attempt to maximize the reach and versatility of NSF, a technique has been described that includes the dissection of the NSF pedicle and its complete release from the SPA foramen [16]. The flap is left attached only to the internal maxillary artery vascular bundle (Fig. 5). This results in improved reach of the flap anteriorly.

A study on NSF complications has been recently published: local and minor complications of the NSF like NSF necrosis, mucocele formation, septal perforation, nasal dorsum collapse, crust forming, synechia, reduced quality of life and olfactory loss are reported in 35% of the patients in this study by Wengier *et al.* [17] The authors propose postoperative measures that reduce occurrence of local complications. To reduce crusting, they suggest harvesting a flap tailored to the defect size and location while trying to elevate as little mucosa as

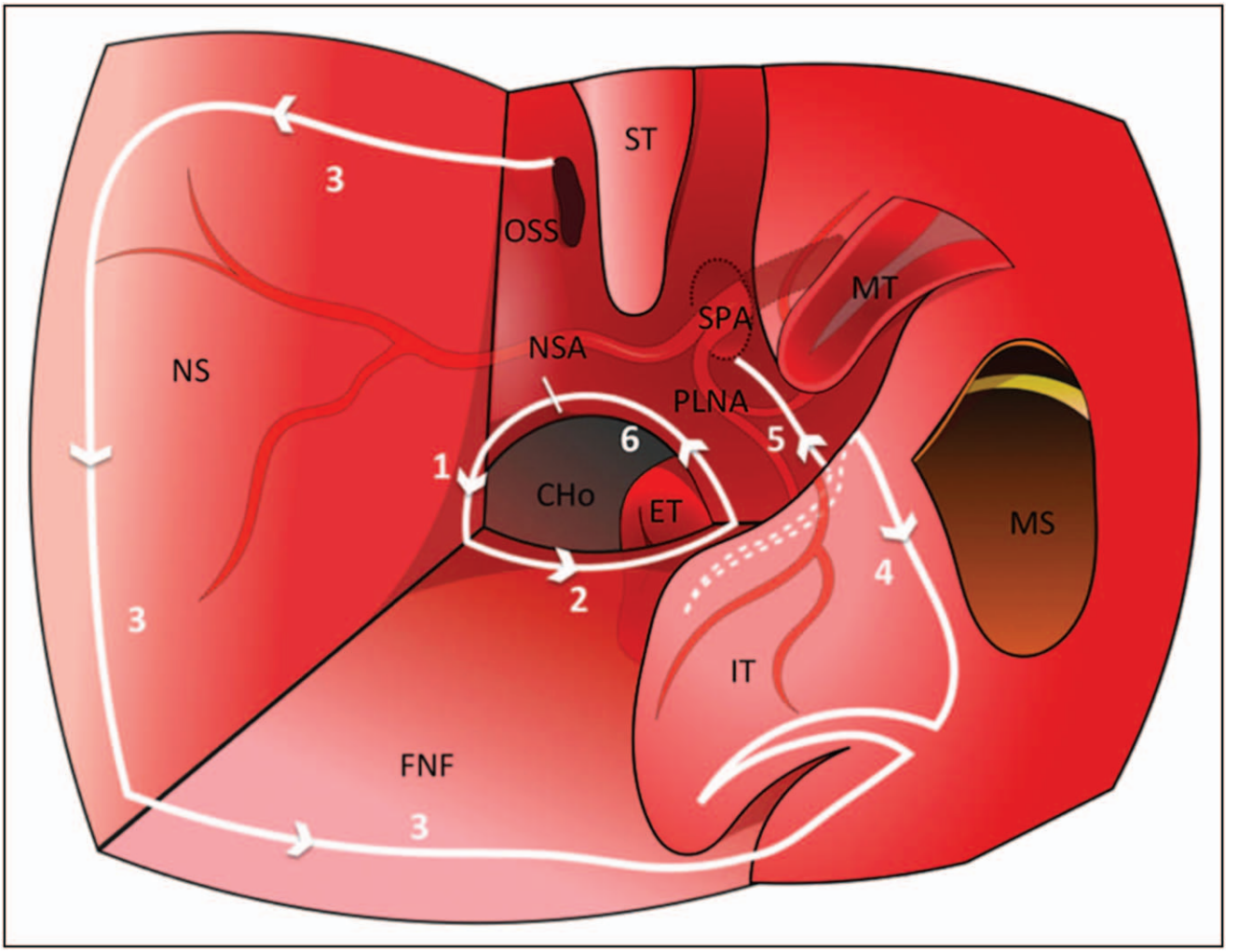

FIGURE 2. Artistic illustration of the mucosal cuts for harvesting a combined IT-NSF. The mucosal cuts are described in the main text. Cho, Choana; ET, Eustachian tube; FNF, floor of the nasal fossa; IT, inferior turbinate; MS, maxillary sinus; MT, middle turbinate; NS, nasal septum; NSA, nasoseptal artery; OSS, ostium of sphenoid sinus; PLNA, posterolateral nasal artery; SPA, sphenopalatine artery; ST, superior turbinate. © 2017, Department of Neurosurgery, Lariboisière Hospital, Paris. Printed with permission. All rights reserved. Reproduced with permission from Boetto *et al.* [13].

possible from the cartilaginous septum, taking care to cover all exposed cartilage at the end of the procedure. A reverse flap could be used for coverage and suturing silicone sheets along the nasal septum and removing them at postoperative day 14 reduces synechia formation and allows for a better mucosal coverage in the early postoperative period. In our practice, we leave the silicone sheets up to 20 days postoperatively with very good results.

Flap vascularity may be compromised by injury to the pedicle or prior to endonasal surgery. Indocyanine green (ICG) near-infrared angiography is proposed to predict the viability of pedicled intranasal flaps during endoscopic skull base surgery [18] and limit flap necrosis. This method for intraoperative evaluation of flap viability might help to better understand the quality of the skull base reconstruction.

Extranasal flaps

When defects in the skull base are too large or too distant for intranasal flaps or when the patient has received extensive radiation, extranasal vascularized flaps are a viable option. The endoscopic-assisted paramedian forehead flap was described in a patient with a sinonasal squamous cell carcinoma after failed surgeries with NSF. In this patient, a novel technique of tunneling a paramedian forehead flap (PMFF) via the nasion [19] was used, with good results.

Two anatomical studies describe a Side-Door Temporoparietal Fascia Flap [20] and a combined

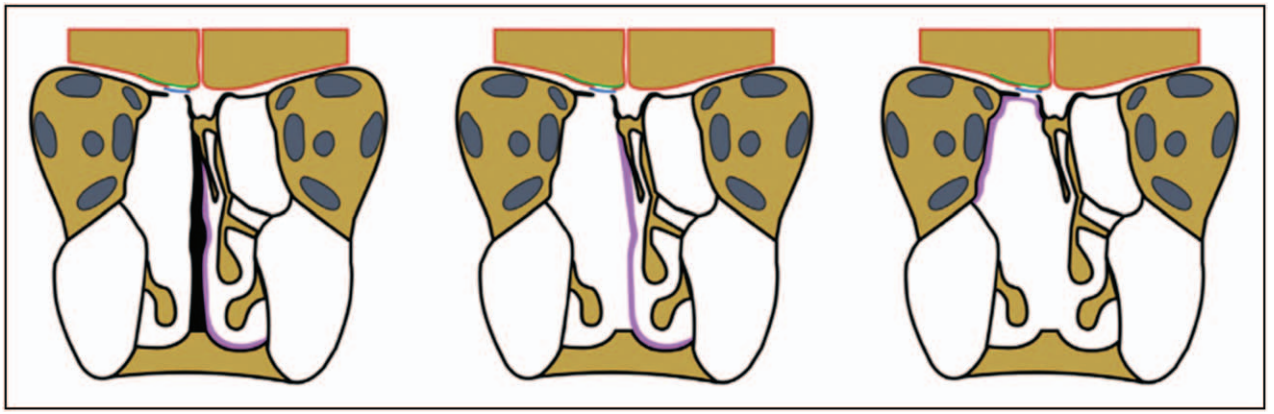

FIGURE 3. Multilayer reconstruction of an anterior skull base defect using septal flip-flap as final layer presented in a stepwise fashion: the red line highlights the dural layer; the green line represents the first layer of iliotibial tract (intradural); the blue lines represent the second layer of iliotibial tract (placed in the epidural gap); and the purple line represents the septal flip-flap resurfacing both the defect and laminal papryceae. Reproduced with permission from Battaglia *et al.* [14].

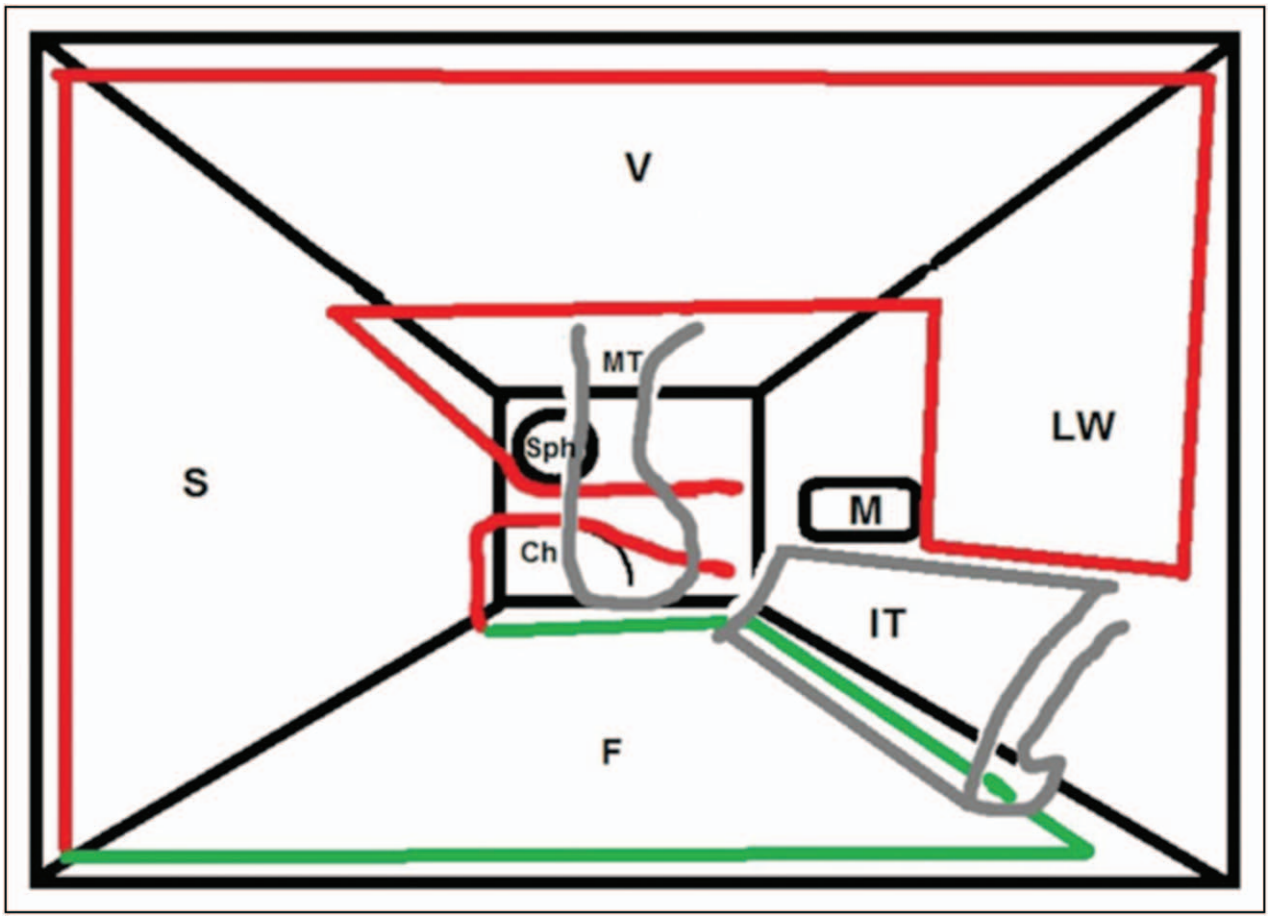

FIGURE 4. Schematic representation of the lateral nasal wall extension of the nasoseptal flap. Ch, choana; F, nasal floor; IT, inferior turbinate; LW, lateral nasal wall; M, maxillary sinus os; MT, middle turbinate; NSF, nasoseptal flap; S, septum; Sph, sphenoid sinus os; V, nasal vault. Reproduced with permission from McCormick *et al.* [15].

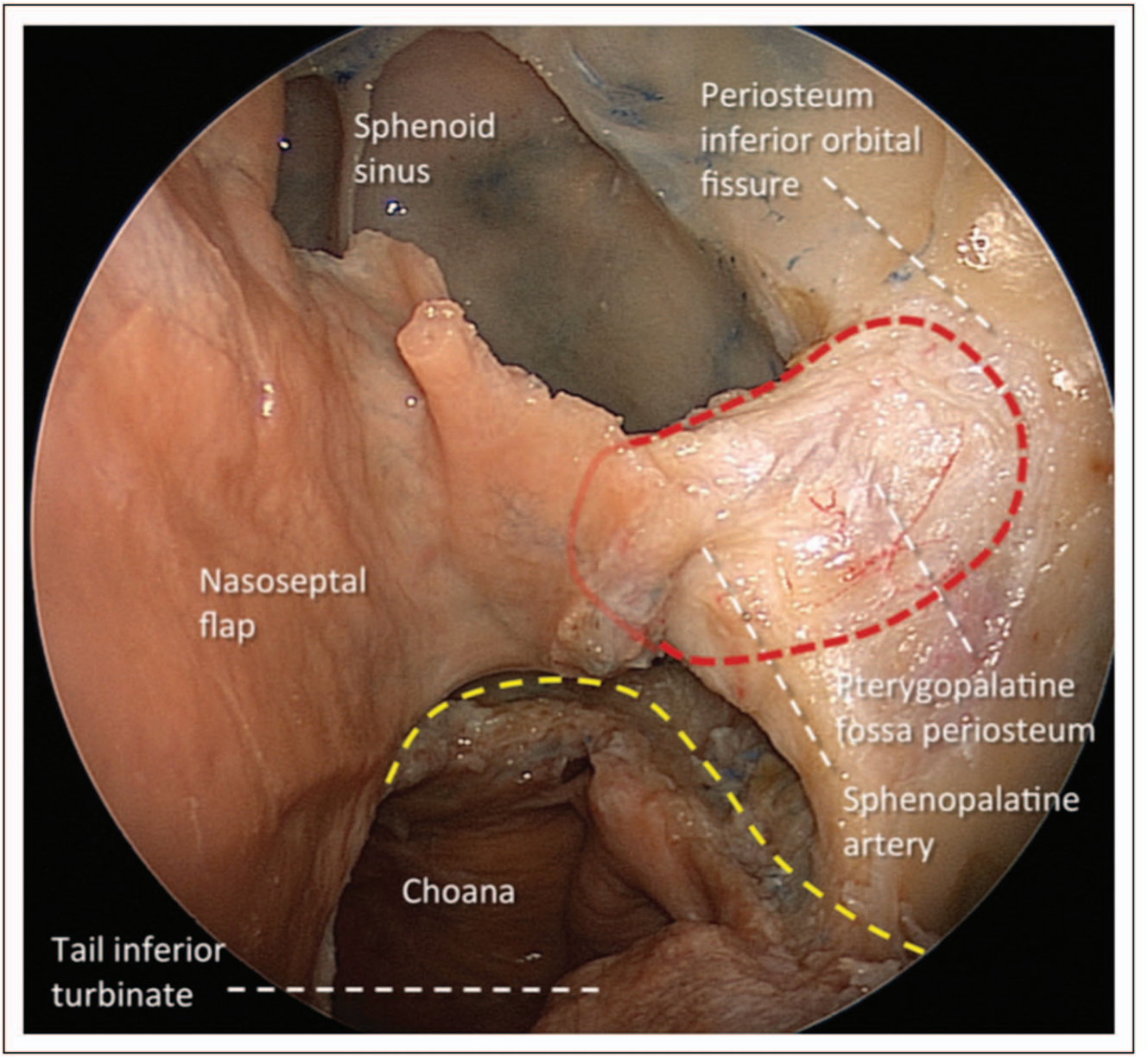

FIGURE 5. Picture obtained with a 0° endoscope from the left nasal cavity during an anatomical dissection. A left side nasoseptal flap was harvested and the osseous boundaries of the sphenopalatine foramen were removed. The yellow dashed line represents the mucosal incision just superior to the inferior turbinate tail to connect the maxillary antrostomy to the incision at the superior aspect of the arch of the choana and release the mucosa of the nasoseptal pedicle laterally. The red dashed line illustrates the 360° periosteal incision required to release completely the sphenopalatine artery from the periosteum of the pterygopalatine fossa. Observe in transparency behind the nasoseptal flap pedicle a continuous red line. This line represents the incision to be completed posterior to the pedicle in order to achieve the 360° circumferential incision around the SPA. Reproduced with permission from Pinheiro-Neto *et al.* [16]. SPA, sphenopalatine artery.

temporal galeofascial flap [21] for anterior skull base reconstruction after large tumour resection. The combined temporal galeofascial flap was used for reconstruction after resection of large tumours by the transmaxillary transpterygoid approach and combines the advantages of both pedicled fascia (on the STA vein and artery) and galeopericranial flaps while because of its anatomical location is always available.

In the case of high-flow clival defects, the first option for reconstruction are local vascularized flaps. When they are not available or have failed, another option is to use a temporoparietal flap. This flap is most suitable for reconstructions of the

middle and inferior clival defects. However, a recent article by Gode *et al.* [22▪] advocates the use of a pericranial flap. Relative advantages of the pericranial flap include accessibility, ease of dissection, reliable blood supply, large dimensions (length and width) and limited morbidity with good cosmesis. As the clivus is an extended application of the pericranial flap, dissection must be directed posteriorly from the bicoronal incision so as to be able to harvest the longest possible flap. The bilateral blood supply (pedicled on one or both supraorbital and supratrochlear vessels) allows for the use of a unilateral flap, preserving the contralateral flap for future reconstructive needs. In their article, 57% of patients (4 out of 7) had a successful reconstruction.

In a patient with a relapse of a sinonasal squamous cell carcinoma affecting the left superomedial orbital region and involving both the frontal sinuses and the frontobasal region, with local erosion of the frontal bone and infiltration of the dura mater, a bilaterally pedicled bitemporoparietal pericranial flap characterized by large pedicles on both STA was used for a successful skull base reconstruction [23]

Vascularized flaps in paediatric patients

Paediatric patients, particularly those below the age of 6 years, present a unique set of challenges in the case of skull base reconstruction. Most prevalent in these patients are encephaloceles while rathke's cleft cysts, pituitary adenomas and chordomas are much more common and limited to the older patients (6–18 years old) [8▪]. Variations between the younger paediatric patients include variable pneumatization, small nasal cavities, limited capacity for blood loss because of smaller total blood volume and postsurgical developmental concerns. In a recent study on the very young paediatric patients, 33% had a successful anterior skull base reconstruction with the use of a standard nasal septal flap whereas others either needed multiple types of grafts or a pericranial flap.

CONCLUSION

Due to evolving and extending endonasal operations, vascularized flaps have become increasingly diversified. New vascularized flaps have been suggested in the last years, some quite similar, whereas some vascularized flaps have already established their value during the last decades.

Important is correct patient selection and their specific tailored flap or combinations of vascularized flaps to reduce minor and major complications.

Acknowledgements

None.

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- ▪ of special interest
- ▪▪ of outstanding interest

1. Oostra A, van Furth W, Georgalas C. Extended endoscopic endonasal skull base surgery: from the sella to the anterior and posterior cranial fossa: endoscopic endonasal skull base surgery. ANZ J Surg 2012; 82:122–130.
2. Kassam A, Carrau R. Expanded endonasal approach: the rostrocaudal axis. Part I. Crista galli to the sella turcica. Neurosurg Focus 2005; 19(E3.).
3. Hadad G, Bassagasteguy L, Carrau RL, *et al.* A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. Laryngoscope 2006; 116:1882–1886.
4. Moon JH, Kim EH, Kim SH. Various modifications of a vascularized nasoseptal flap for repair of extensive skull base dural defects. J Neurosurg 2020; 132:371–379.
5. ▪▪ Bozkurt G, Leone F, Arosio AD, *et al.* Septal flip flap for anterior skull base reconstruction after endoscopic transnasal craniectomy: long-term outcomes. World Neurosurg 2019; 128:e409–e416.

This study describes the long-term outcome of the use of the novel flip-flap vascular intranasal flap. This novel flap has the ability to reach a more anterior coverage without the use of an extranasal flap.

6. Kim GG, Hang AX, Mitchell CA, Zanation AM. Pedicled extranasal flaps in skull base reconstruction. In: Bleier BS, editor. Advances in otorhinolaryngology. Basel: S. KARGER AG; 2012. pp. 71–80.
7. Zanation AM, Thorp BD, Parmar P, Harvey RJ. Reconstructive options for endoscopic skull base surgery. Otolaryngol Clin North Am 2011; 44:1201–1222.
8. ▪ London NR, Rangel GG, Onwuka A, *et al.* Reconstruction of pediatric skull base defects: a retrospective analysis emphasizing the very young. Int J Pediatr Otorhinolaryngol 2020; 133:109962.

This study highlights the use of the intranasal flaps or combinations in a patient group not previously described, namely very young children (until the age of 6).

9. Fortes FSG, Carrau RL, Snyderman CH. The posterior pedicle inferior turbinate flap: a new vascularized flap for skull base reconstruction. Laryngoscope 2007; 17:1329–1332.
10. Kutlay M, Durmaz F, Kırık A, *et al.* Sellar defect reconstruction with vascularized superior turbinate mucosal flaps in endonasal endoscopic transsellar approach. World Neurosurg 2019; 133:e503–e512.
11. ▪ Kuan E, trent M, Palmer J. Preventing restenosis of marsupialized rathke cleft cysts using a nasoseptal flap lining. Laryngoscope 2019; 129:2258–2261.

This study shows a new use of the standard nasoseptal flap, using the flap not only to reconstruct the anterior skull base but also lining the floor of the cavity created after removal of a rathke cyst.

12. Georgalas C, Kania R, Guichard J-P, *et al.* Endoscopic transsphenoidal surgery for cholesterol granulomas involving the petrous apex. Clin Otolaryngol 2008; 33:38–42.
13. Boetto J, Labidi M, Watanabe K, *et al.* Combined nasoseptal and inferior turbinate flap for reconstruction of large skull base defect after expanded endonasal approach: operative technique. Oper Neurosurg (Hagerstown) 2019; 16:45–52.
14. Battaglia P, Turri-Zanoni M, Bernardi FD, *et al.* Septal flip flap for anterior skull base reconstruction after endoscopic resection of sinonasal cancers: preliminary outcomes. Acta Otorhinolaryngol Ital 2016; 36:194–1985.
15. McCormick J, Allen M, Kain JJ, *et al.* Lateral nasal wall extension of the nasoseptal flap for skull-base and medial orbital wall defects. Int Forum Allergy Rhinol 2019; 9:1041–1045.
16. Pinheiro-Neto CD, Peris-Celda M, Kenning T. Extrapolating the limits of the nasoseptal flap with pedicle dissection to the internal maxillary artery. Oper Neurosurg (Hagerstown) 2019; 16:37–44.
17. Wengier A, Ram Z, Warshavsky A, *et al.* Endoscopic skull base reconstruction with the nasoseptal flap: complications and risk factors. Eur Arch Otorhinolaryngol 2019; 276:2491–2498.
18. Geltzeiler M, Nakassa ACI, Turner M, *et al.* Evaluation of intranasal flap perfusion by intraoperative indocyanine green fluorescence angiography. Oper Neurosurg 2018; 15:672–676.

19. Bresler AY, Mir G, Grube J, *et al.* Endoscopic paramedian forehead flap reconstruction of the anterior skull base for recalcitrant cerebrospinal fluid leaks: minimally invasive adaptation of ancient flap. World Neurosurg 2019; 130:37–41.
20. Ferrari M, Vural A, Schreiber A, *et al.* Side-door temporoparietal fascia flap: a novel strategy for anterior skull base reconstruction. World Neurosurg 2019; 126:e360–e370.
21. Gagliardi F, Boari N, Piloni M, *et al.* Temporal galeofascial flap for reconstruction after transmaxillary approaches to the clival region. World Neurosurg 2020; 134:e68–e74.
22. Gode S, Lieber S, Nakassa ACI, *et al.* Clinical experience with secondary ■ endoscopic reconstruction of clival defects with extracranial pericranial flaps. J Neurol Surg Part B Skull Base 2019; 80:276–282.
This study highlights the need for tailored reconstructions of the anterior skull base, when intranasal flaps are not available (because of previous surgery of radiotherapy) extranasal or pericranial flaps can be very useful.
23. Tabano A, Restelli F, Pozzi F, *et al.* The helmet-visor pericranial flap as a viable option for anterior cranial base reconstruction in complex oncologic cases. World Neurosurg 2019; 128:506–513.