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Cranial–base surgery: a reconstructive algorithm

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SUMMARY. Skull–base surgery is associated with a high risk of cerebrospinal fluid (CSF) leak, infection, and functional and aesthetic deformity. Appropriate reconstruction of cranial–base defects following surgery helps to prevent these complications. Between March 1998 and May 2000, 28 patients (age: 1–68 years) underwent reconstruction of the anterior and middle cranial fossae. The indications for surgery were tumours, trauma involving the anterior cranial fossa, midline dermoid cysts with intracranial extension, late post-traumatic CSF leak, craniofacial deformity and recurrent frontal mucocoele. We used local anteriorly based pericranial flaps (23 flaps, alone or in combination with other flaps), bipedicled galeal flaps (seven patients) and free flaps (nine patients; radial forearm fascial/fasciocutaneous flaps, rectus abdominis muscle flap and latissimus dorsi muscle flap). Follow-up has been 4–24 months. We had no deaths, no flap failure and no incidence of infection. Complications included two CSF leaks, three intracranial haematomas and one pulsatile enophthalmos. All patients had a very good aesthetic result. We present an algorithm for skull–base reconstruction and comment on the design and vascularity of the bipedicled galeal flap. The monitoring of intracranial flaps and the difficulties of perioperative management of free flaps in neurosurgical patients are also discussed.

Keywords: cranial–base reconstruction, algorithm, pericranial flaps, galeal flaps, free flaps.

The cranial base is a complex structure that separates the intracranial from the extracranial tissues and through which vital vessels and nerves are transmitted. Its internal surface is in three levels,[1] like the steps of a staircase: the anterior cranial fossa, which lies highest of the three, the middle cranial fossa, which is butterfly shaped, and the posterior cranial fossa, which is deeply concave and lies above the foramen magnum. Defects of the skull base can be the result of tumour resection, trauma or a requirement for access osteotomy. Traditional neurosurgical practice has been to cover these defects with layers of non-vascularised grafts, such as pericranium, temporalis fascia, fascia lata, muscle and fat, and materials such as allograft or synthetic dura, surgical cellulose mesh, etc. This traditional practice can lead to necrosis, cerebrospinal fluid (CSF) leak and infection. These may progress to potentially fatal meningitis and cerebral abscesses. Other complications[2–4] of skull–base surgery include neurological and ocular complications, vascular injury, thrombosis, haemorrhage, osteomyelitis, bone resorption, pneumocephalus, pulsatile exophthalmos and aesthetic deformity. The use of vascularised tissue, in the form of local or free flaps, has significantly reduced the associated morbidity and mortality,[5–7] while advances in access osteotomies[8] have enabled the resection of tumours that were previously considered inoperable.

As a team, following a review of published work and after our earliest experiences, we constructed an algorithm for reconstruction of defects of the anterior and middle cranial fossae. This was applied to our subsequent patients. The principles of our practice and the results of the combined neurosurgical–plastic surgical approach are presented.

Patients and methods

The reconstructive algorithm (Fig. 1) was developed as a guide to clinical practice. Any skull–base defect that allows communication of the intracranial contents with the nose or the paranasal sinuses requires reconstruction. If the patient has had no previous radiotherapy, surgery or trauma, selection of the reconstructive method depends on the size of the bony defect. A minimal defect is equivalent to a ‘saw cut’ defect, resulting from an access osteotomy. This can be covered with a pericranial flap. A moderate-sized defect, resulting from a comminuted basal fracture or minimal bone resection, requires a thicker but still pliable flap, such as a galeal flap or a thin free flap. A large defect results from significant bone resection and is usually associated with tumour and/or brain resection. This size of defect requires a bulkier free flap to separate the intracranial from the extracranial space and to obliterate the intracranial dead space. Previous radiotherapy precludes the use of local flaps and necessitates a free flap, whereas

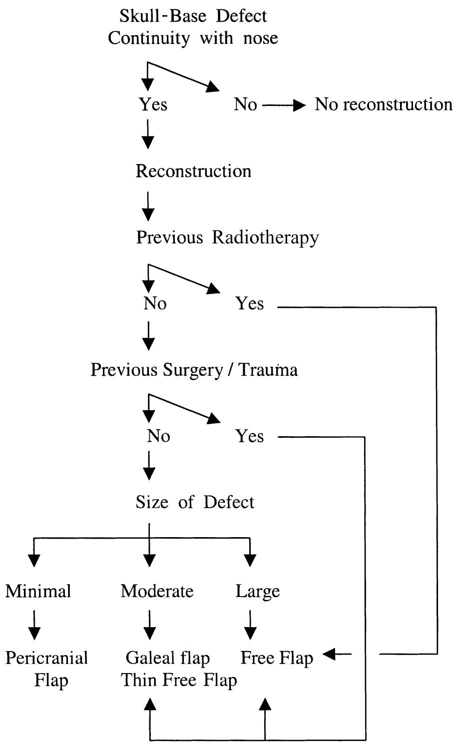

Figure 1—Algorithm for reconstructing the anterior/middle cranial fossa.

previous surgery or trauma results in devascularised pericranium and therefore requires a galeal flap or a free flap.

Other aspects of our practice include:

- Scalp incisions are planned so as to preserve and maximise the use of local flaps, while preserving blood vessels that can potentially be used for anastomosis of free flaps.
- The classical neurosurgical bicoronal scalp incision is modified to a zig-zag, starting very close to the ear and going backwards, to ensure that the superficial temporal vessels are preserved.
- Supraorbital and orbitozygomatic osteotomies are commonly performed, in addition to frontal craniotomy.
- The frontal sinuses are always cranialised and the nasofrontal ducts are plugged with bone graft. The sinuses are covered with a pericranial flap.
- Split calvarial bone grafts are used to reconstruct bony defects of the facial skeleton and to avoid the risk of pulsatile exophthalmos from transmitted brain pulsations to the globe.
- Fibrin glue is used to provide a watertight seal of the flaps.
- Rigid fixation of the bone fragments is used to stabilise the skeleton in its normal position.
- Postoperatively, patients are admitted to the High Dependency Unit and monitored for neurological and medical complications, bleeding and infection.
- Prophylactic antibiotics (cefuroxime and metronidazole) are given for a total of 5 days (intravenously for 48–72 h, converting to orally when tolerated) until an airtight and watertight seal has been established.

Table 1 Indications for cranial–base surgery and reconstruction

tumour	11
meningioma	7
recurrent malignant schwannoma	1
recurrent basal cell carcinoma	1
malignant cylindroma	1
leiomyosarcoma	1
trauma	8
midline intracranial dermoid	3
post-traumatic CSF leak	3
craniofacial deformity	2
recurrent frontal mucocoele	1

Having followed the above principles, we decided to review our results and assess the efficacy of the algorithm. Overall, 28 patients, aged between 1 year and 68 years, required reconstruction of the cranial base between March 1999 and July 2000.

All defects involved the anterior cranial fossa, allowing communication with the nose or paranasal sinuses. Additionally, 14 of these defects extended to and partially involved the middle cranial fossa. The case notes were studied to determine postoperative complications, and the patients were reviewed in the outpatient clinic. The follow-up so far is between 4 and 24 months.

Table 1 shows the indications for surgery. The commonest type of tumour was intraosseous meningioma, requiring resection of the sphenoid bone. Other indications included craniofacial trauma with fractures of the anterior cranial fossa and evidence of dural tear, midline dermoid cysts with intracranial extension, and late post-traumatic CSF leaks that were referred to us between 3 months and 20 years after the initial injury.

Results

We used 23 pericranial flaps (alone or in combination with other flaps), eight galeal flaps and nine free flaps (Table 2). All pericranial flaps were based anteriorly (Fig. 2) on the deep branches of the supraorbital and supratrochlear vessels. All galeal flaps (Fig. 3) were raised as bipedicled flaps, based on both superficial temporal vessels, and were transposed intracranially, like a visor, to cover the defect on the skull base.

The free flaps used were the radial forearm fascial or fasciocutaneous flap, the rectus abdominis muscle flap and the latissimus dorsi muscle flap, with the superficial temporal vessels usually being the recipient vessels.

We had no deaths, no flap loss and no incidence of infection. Two patients with craniofacial trauma developed CSF leak. The first had severe multiple trauma following a road-traffic accident, with extensive craniofacial fractures and cerebral contusions. Her poor general condition necessitated the use of a simple galeal flap. The second patient had persistent CSF leak following craniofacial trauma 20 years previously. Pericranial and galeal flaps were used. In retrospect, we believe that we

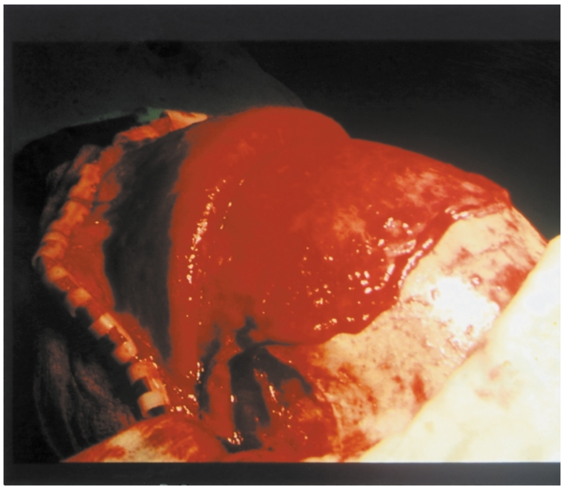

Figure 2—Anteriorly based pericranial flap, raised before craniotomy (the bicoronal scalp flap has been reflected anteriorly).

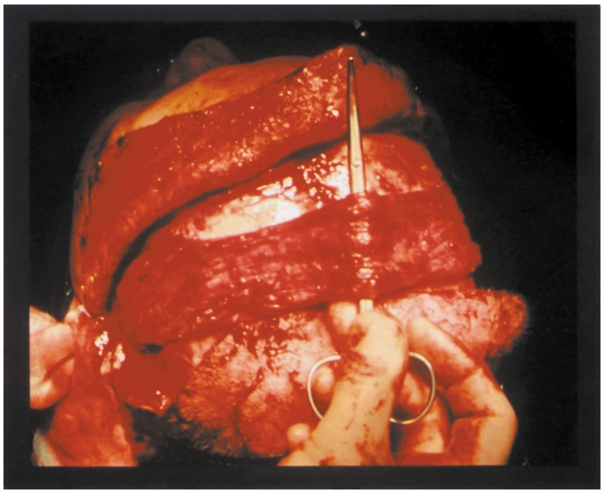

Figure 3—Bipedicled galeal flap (scissors pointing anteriorly).

underestimated the extent of the defect. In both cases, the leak was treated successfully with a free radial forearm fascial flap. Three patients developed extradural haematoma following resection of meningioma. The collection developed despite the use of suction drains and required drainage in the early postoperative period. None of the haematomas was related to the flap used (one free radial forearm fascial flap and two pericranial flaps). The flaps were not adversely affected by either the haematoma or the subsequent evacuation. One patient developed pulsatile enophthalmos due to resorption of a bone graft. This has now been corrected. All the patients had a very good aesthetic result.

Discussion

Skull–base surgery has evolved as a subspecialty of neurosurgery. Current practice involves a multidisciplinary approach, encompassing neurosurgery, plastic surgery, maxillofacial surgery and ophthalmology. Specialists in neuroradiology, oncology and neurorehabilitation also contribute to the team. As part of the preoperative planning, the reconstructive algorithm was developed by the team, in accordance with current principles for use of vascularised tissue. It involves the use of local and free flaps according to the size of the bony defect and the history of radiotherapy, surgery or trauma. These flaps provide watertight separation of the intracranial space from the nasopharynx, preventing CSF leak and ascending infection.

Table 2 Flaps used for cranial base reconstruction

pericranial flaps	23
galeal flaps	8
free flaps	9
rectus abdominis muscle	4
radial forearm fascial	2
radial forearm fasciocutaneous	2
latissimus dorsi muscle	1
recipient vessels	
superficial temporal	7
facial	2

The use of pericranial[9–12] and galeal flaps has been described by many authors. All our pericranial flaps were based anteriorly, on the deep branches of the supraorbital and supratrochlear vessels. Although this type of flap is thin, its vascularity is very good (unless compromised by trauma, previous surgery or radiotherapy) and it can cover the whole anterior cranial fossa. It is such an easy flap to raise that it has become routine practice to elevate the coronal scalp flap preserving a separate pericranial flap, which is used to line the anterior cranial fossa and augment any other flap used.

The galeal flap is thicker than the pericranial flap but still pliable. It can be raised as an anteriorly based (galeofrontalis) flap,[13,14] a posteriorly based (galeo-occipitalis)[15] flap or a laterally based[16] (unilateral or bilateral) flap. The galeofrontalis flap has the disadvantages of producing visible irregularities on the forehead and leaving the forehead skin very thin and vulnerable to breakdown. The galeo-occipitalis flap is not suitable to cover the anterior or middle cranial fossa. Laterally based flaps are commonly used. Cadaver studies[17] have demonstrated that an ipsilateral superficial temporal artery that supplies a laterally based galeal flap does not cross the midline or anastomose with the contralateral superficial temporal artery but ensures the survival of a flap extended up to 1 cm proximal to the sagittal suture line. This fact limits the reconstructive potential of this flap. In our series of anterior and middle cranial fossae defects, we have used the bipedicled galeal flap, which is based on both superficial temporal vessels, can be raised with a width of up to 15 cm and is transposed intracranially, like a visor, through a burr hole or craniotomy site anterior to or deep to the temporalis muscle on each side. To enable this, the temporalis muscle is often detached superiorly and mobilised posteriorly to a varying degree, depending on the level of craniotomy. At the end of the procedure, the muscle is reattached to bone, fascial cuff or plate in such way that the vascularity of the flap is not compromised.

Free tissue transfer offers flexibility in flap design and quantity of tissue, and has a high success rate.[18–25] The free flaps we used were the radial forearm flap (fascial or fasciocutaneous), the rectus abdominis muscle flap and the latissimus dorsi muscle flap. These flaps are highly reliable, have a long pedicle and can provide the necessary bulk to obliterate a large dead space. Our recipient vessels of choice are the superficial temporal vessels. However, these vessels are occasionally of small calibre and may be unsuitable for anastomosis. This was the case in two patients, in which the facial vessels were used instead. Most of the free flaps are completely buried, and monitoring is extremely difficult. None of the known monitoring methods can be applied to intracranial flaps; their viability and effectiveness are implied by the lack of complications. It is, therefore, important to have an experienced microsurgical team and to use highly reliable flaps.

The perioperative management of neurosurgical patients differs significantly from the management of patients with free flaps. In neurosurgical anaesthesia, vasodilation is avoided and fluid administration aims to maintain a slightly negative fluid balance. The choice of anaesthetic agents and postoperative analgesics is different, i.e. opioids are avoided in neurosurgery, as they increase $PaCO_2$ and cause vasodilation. Diuretics and steroids are sometimes used. The ideal perioperative conditions for free flaps are exactly the opposite. As plastic surgeons, we have compromised on all the above factors and, so far, we have not lost or needed to re-explore any of our flaps.

By following the algorithm, we had a low incidence of complications. None of the haematomas was related to the flap used or the microsurgical anastomosis. We had two cases of CSF leak. The first was in a patient with multiple trauma and severe cranial–base fractures, whose poor general condition necessitated the use of a simple galeal flap following reduction of the fractures. After her condition was stabilised it became apparent that there was a leak. This was repaired with a free radial forearm flap. The second patient had recurrent CSF leak following old trauma.

In cases of tumours involving the cranial base, resection was performed with a curative intent. At the time of writing, no recurrences have been observed. However, the follow-up is too short to evaluate the risk of recurrence.

We found that our algorithm can successfully address the reconstructive requirements of the cranial base. Use of pericranial, galeal and free flaps, as indicated, can provide reliable reconstruction of a wide spectrum of anterior and middle cranial fossae defects.

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References

1. Sinnatamby CS. *Last's Anatomy. Regional and Applied*, 10th ed. Edinburgh: Churchill Livingstone; 1999. p. 504.
2. Boyle JO, Shah KC, Shah JP. Craniofacial resection for malignant neoplasms of the skull base: an overview. J Surg Oncol 1998;69: 275–84.
3. Nibu K, Sasaki T, Kawahara N, et al. Complications of craniofacial surgery for tumours involving the anterior cranial base. Neurosurgery 1998;42:455–62.
4. Nguyen TT, Delashaw JB. Complications of skull base surgery. Clin Plast Surg 1995;22:573–80.
5. Jones NF, Schramm VL, Sekhar LN. Reconstruction of the cranial base following tumour resection. Br J Plast Surg 1987;40:155–62.
6. Janecka IP, Sekhar LN. Surgical management of cranial base tumours: a report on 91 patients. Oncology 1989;3:69–74.
7. Spinelli HM, Persing JA, Walser B. Reconstruction of the cranial base. Clin Plast Surg 1995;22:555–61.
8. Jackson IT, Marsh WR, Bite U, Hide TAH. Craniofacial osteotomies to facilitate skull base tumour resection. Br J Plast Surg 1986;39:153–60.
9. Argenta LC, Friedman RJ, Dingman RO, Duua EC. The versatility of pericranial flaps. Plast Reconstr Surg 1985;76:695–702.
10. Snyderman CH, Janecka IP, Sekhar LN, Sen CN, Eibling DE. Anterior cranial base reconstruction: role of galeal and pericranial flaps. Laryngoscope 1990;100:607–14.
11. Price JC, Loury M, Carson B, Johns ME. The pericranial flap for reconstruction of anterior skull base defects. Laryngoscope 1988; 98:1159–64.
12. Johns ME, Winn HR, McLean WC. Pericranial flap for closure of defects of craniofacial resection. Laryngoscope 1981;91:952–9.
13. Jackson IT, Adham MN, Marsh R. Use of the galeal frontalis myofascial flap in craniofacial surgery. Plast Reconstr Surg 1986;77: 905–10.
14. Fukuta K, Potparic Z, Sugihara T, et al. A cadaver investigation of the blood supply of the galeal frontalis flap. Plast Reconstr Surg 1994;94:794–800.
15. Sharma RK, Kobayashi K, Jackson IT, Carls FR. Vascular anatomy of the galeal occipitalis flap: a cadaver study. Plast Reconstr Surg 1996;97:25–31.
16. Avelar JM, Psillakis JM. The use of galea flaps in craniofacial deformities. Ann Plast Surg 1981;6:464–9.
17. Har-Shai Y, Fukuta K, Collares MV, et al. The vascular anatomy of the galeal flap in the interparietal and midline regions. Plast Reconstr Surg 1992;89:64–9.
18. Thompson JG, Restifo RJ. Microsurgery for cranial base tumors. Clin Plast Surg 1995;22:563–72.
19. Aspoas AR, Wilson GR, McLean NR, Mendelow AD, Crawford PJ. Microvascular reconstruction of complex craniofacial defects. Ann R Coll Surg Engl 1997;79:278–83.
20. Schliephake H, Schmelzeisen R, Samii M, Sollmann WP. Microvascular reconstruction of the skull base: indications and procedures. J Oral Maxillofac Surg 1999;57:233–9.
21. Joos U, Mann W, Gilsbach J. Microsurgical treatment of midfacial tumours involving the skull base. J Craniomaxillofac Surg 1998; 26:226–34.
22. Fisher J, Jackson IT. Microvascular surgery as an adjunct to craniomaxillofacial reconstruction. Br J Plast Surg 1989;42:146–54.
23. Disa J, Rodriguez VM, Cordeiro PG. Reconstruction of lateral skull base oncological defects: the role of free tissue transfer. Ann Plast Surg 1998;41:633–9.
24. Mustoe TA, Corral CJ. Soft tissue reconstructive choices for craniofacial reconstruction. Clin Plast Surg 1995;22:543–54.
25. Jones NF, Sekhar LN, Schramm VL. Free rectus abdominis muscle flap reconstruction of the middle and posterior cranial base. Plast Reconstr Surg 1986;78:471–7.

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