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Reconstruction of the cranial base following tumour resection

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Summary—Twenty-four patients have undergone resection of tumours involving the cranial base by a multidisciplinary team consisting of a neurosurgeon, ENT surgeon and plastic surgeon. The resultant defects of the cranial base have been reconstructed using local fascial flaps, transposition of local muscle flaps and microsurgical transfer of free muscle flaps. Indications for reconstruction have included obliteration of paranasal sinuses, coverage of tenuous dural repairs or dural grafts and separation of the nasopharynx from the dura of the frontal and temporal lobes and posterior fossa to prevent CSF leakage and meningitis.

The skull base may be involved by intracranial tumours extending inferiorly through the various foramina or by extracranial tumours invading superiorly into the skull base and intradural compartment. With recent advances in CT scanning and NMR scanning, preoperative localisation of these tumours has become better defined, especially their intracranial and extracranial extension. Craniofacial techniques have allowed improved exposure of the skull base. However, because of the close proximity of the paranasal sinuses and nasopharynx to the dura following resection of these tumours, leakage of CSF through a dural repair may allow infection to ascend from the nasopharynx or paranasal sinuses into the intradural space to produce meningitis. Many of these tumours have been considered inoperable for this reason and consequently, reliable methods of isolating the dural repair or dural graft from the nasopharynx and paranasal sinuses become absolutely crucial to allow surgical resection of these skull base tumours.

Materials and Methods

From July 1984 until December 1985, 24 patients aged 3 to 79 years have undergone resection of tumours involving the anterior, middle and posterior cranial base and subsequent reconstruction by a multidisciplinary team consisting of a neurosurgeon, ENT surgeon and plastic surgeon. A bicoronal incision and bifrontal craniotomy have been utilised in the exposure of tumours involving the anterior cranial base. Two approaches have been used for the extradural exposure of tumours involving the middle and posterior cranial base. In the infratemporal approach (Sekhar *et al*, 1986), a hemicoronal incision with a pre-auricular extension allows resection of the mandibular condyle and inferior displacement of the zygomatic arch, after dissection of the facial nerve from the stylomastoid foramen into the parotid gland. The entire petrous course of the internal carotid artery may then be exposed and dissected free of tumour into the cavernous sinus. In the transtemporal approach (Fisch *et al.*, 1984) a hemicoronal incision is extended behind the ear and the external ear canal transected. A radical mastoidectomy is performed to expose the facial nerve from the geniculate ganglion into the parotid gland and the nerve permanently transposed anteriorly. The involved petrous temporal bone is drilled away as before to free the internal carotid artery up to the cavernous sinus. The intradural component of tumours involving the sphenoid ridge, middle cranial fossa, cavernous sinus and upper clivus may be removed through a frontotemporal craniotomy. If the tumour occupies the cerebellopontine angle, jugular foramen and foramen magnum, a retromastoid craniectomy is used.

Following resection of midline tumours of the anterior cranial base, the dural repair or dural graft overlying the frontal lobes is in close proximity to the open frontal and ethmoid sinuses and the roof of the nasopharynx. The galeal flap has been used to reconstruct these midline defects, separating the frontal dura from the exposed frontal and ethmoid sinuses and the nasopharynx. A local flap of galea may be separated off the bicoronal scalp flap based on one or both of the supratrochlear or supraorbital vessels (Fig. 1 A and B).

Lateral defects of the anterior cranial base have been reconstructed using the temporalis muscle. The muscle is elevated together with the periosteum deep to it and the superficial attachments to the zygomatic arch divided transversely. The muscle remains attached to the coronoid process to preserve its blood supply from the internal maxillary artery. The temporalis muscle may then be transposed medially to cover the exposed dura of the anterior cranial fossa. For massive defects of the anterior cranial base, the latissimus dorsi muscle has been utilised as a free muscle flap with microsurgical anastomoses to branches of the external carotid artery and external jugular vein.

Following resection of tumours involving the middle or posterior cranial base, the resultant defect usually consists of an opening of the posterior and lateral walls of the nasopharynx and an exposed sphenoid sinus, both of which are immediately adjacent to either a tenuous dural repair or a dural graft overlying the temporal lobe and posterior fossa. Small lateral defects of the middle or posterior cranial base have been reconstructed by an inferior and medial transposition of the temporalis muscle. (Fig. 2 A, B, and C). For larger medially situated defects and especially those in which there is a large defect in the posterior and lateral walls of the nasopharynx, free rectus abdominis muscle flaps have been used (Jones *et al.*, 1985). The rectus muscle is sutured to the posterior and lateral borders of the defect in the nasopharynx; the internal surface of the muscle within the nasopharynx has not required skin grafting and rapidly epithelialises within several days. Tongues of muscle have been used to obliterate the open sphenoid sinus and the remainder of the muscle draped to cover the exposed dural repair or dural graft overlying the temporal lobe and posterior fossa (Fig. 3 A and B). Occasionally part of the muscle has been used to cover an exposed saphenous vein graft reconstruction of the internal carotid artery should this have required resection due to involvement by tumour. The deep inferior epigastric artery has been anastomosed to either the occipital artery or the stump of the external carotid artery and the two deep inferior epigastric veins anastomosed to the stump of the internal or external jugular veins.

Results

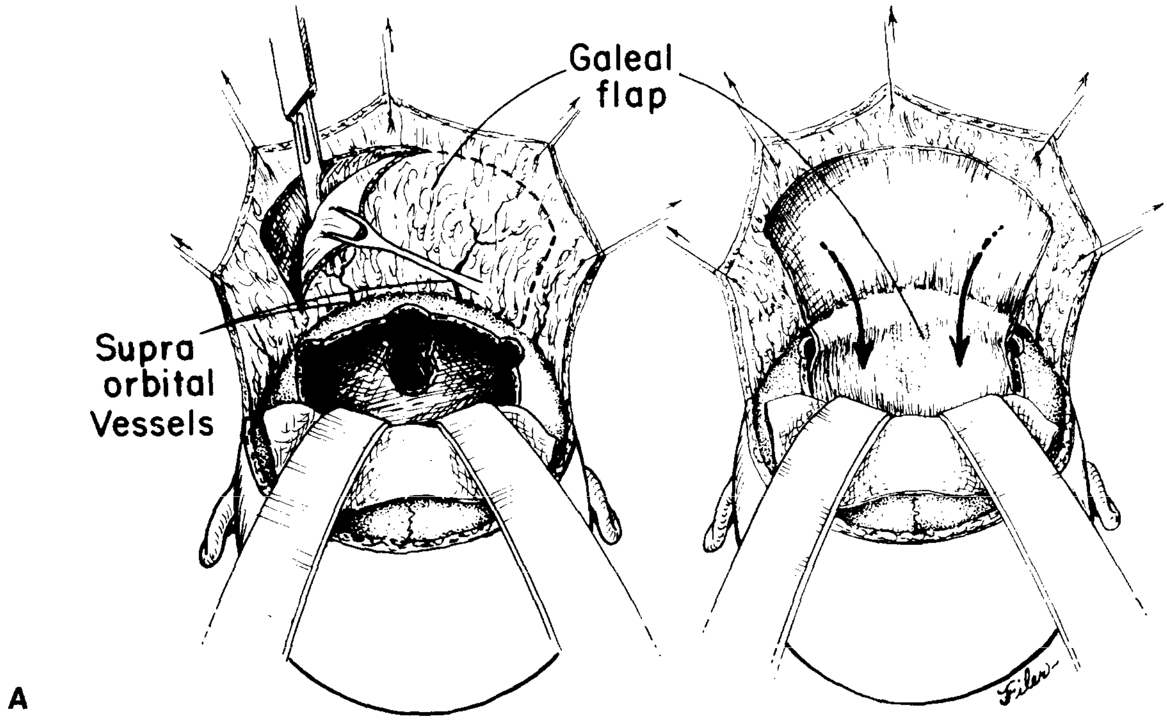
The defects requiring reconstruction, resulting from resection of skull base tumours, involved the anterior cranial base in 7 patients, the middle cranial base in 3 patients, the middle and posterior cranial base in 8 patients and the posterior cranial base in 5 patients. One patient with a massive chordoma of the clivus had involvement of the anterior, middle and posterior cranial base and required two separate resection and reconstructive procedures. Table 1 provides the pathological diagnosis of each tumour and Table 2 the resultant defects of the cranial base that required reconstruction following resection of the tumour. Six galeal flaps were used for reconstruction of midline defects of the anterior cranial fossa. Two patients with massive defects involving the lateral aspect of the anterior cranial base required free latissimus dorsi muscle flaps and split thickness skin grafts for coverage. Of the 17 patients with tumours involving the middle and posterior skull base, 10 patients underwent reconstruction using the temporalis muscle. Seven patients in whom the defect was more medially situated or in which the nasopharynx was in direct communication with the dura of the temporal lobe, required free rectus abdominis muscle flap transfer to separate the dura of the temporal lobe or posterior fossa from the nasopharynx or the paranasal sinuses. Two patients who

Table 1 Tumours involving the cranial base

Basal Cell Carcinoma	1
Melanoma	1
Squamous Cell Carcinoma of Maxillary Antrum	1
Chondrosarcoma	1
Esthesioneuroblastoma	1
Undifferentiated Carcinoma	2
Clivus Chordoma	2
Ameloblastoma	1
Adenoid Cystic Carcinoma	2
Nasopharyngeal Carcinoma	3
Epidermoid	1
Extracranial Meningioma	2
Rhabdomyosarcoma	1
Glomus Tumour	3
Schwannoma	2

Table 2 Defects requiring reconstruction

Anterior Cranial Base	7
Middle Cranial Base	3
Middle and Posterior Cranial Base	8
Posterior Cranial Base	5
Anterior, Middle and Posterior Cranial Base	1
Dural Graft	12
Open Nasopharynx	15



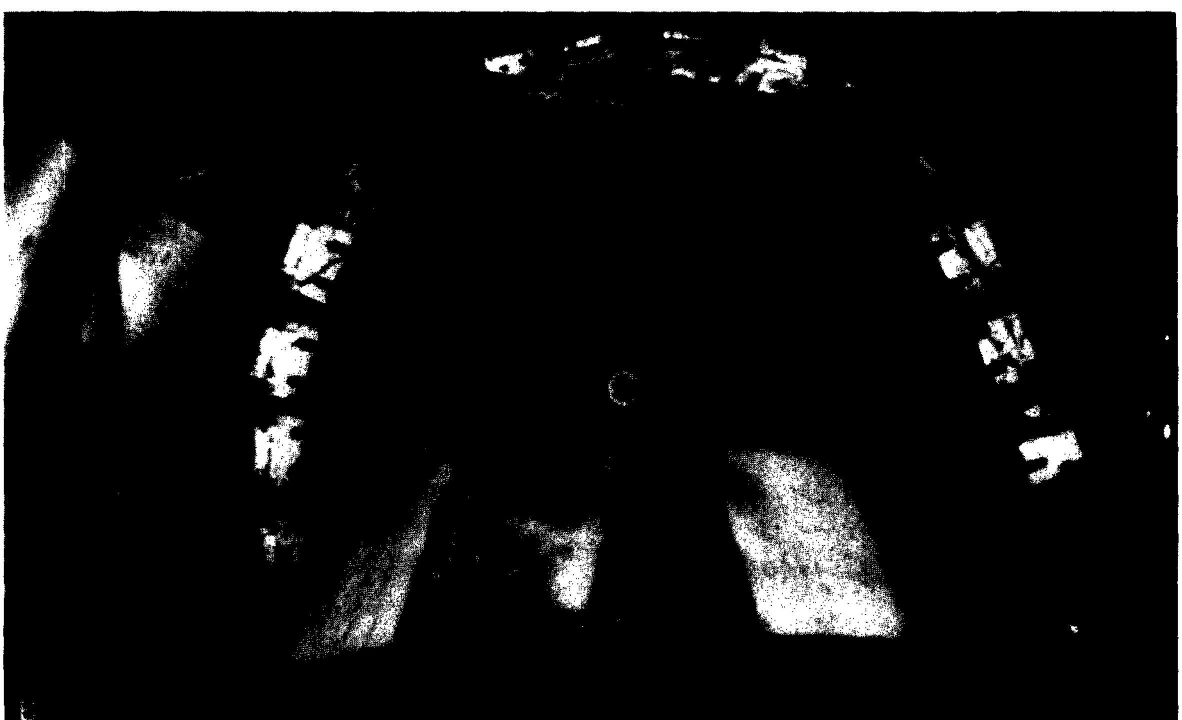


Fig. 1

Figure 1 (A and B)—Elevation of galeal flap from the bicoronal scalping flap to cover a midline defect of the floor of the anterior cranial fossa (C).

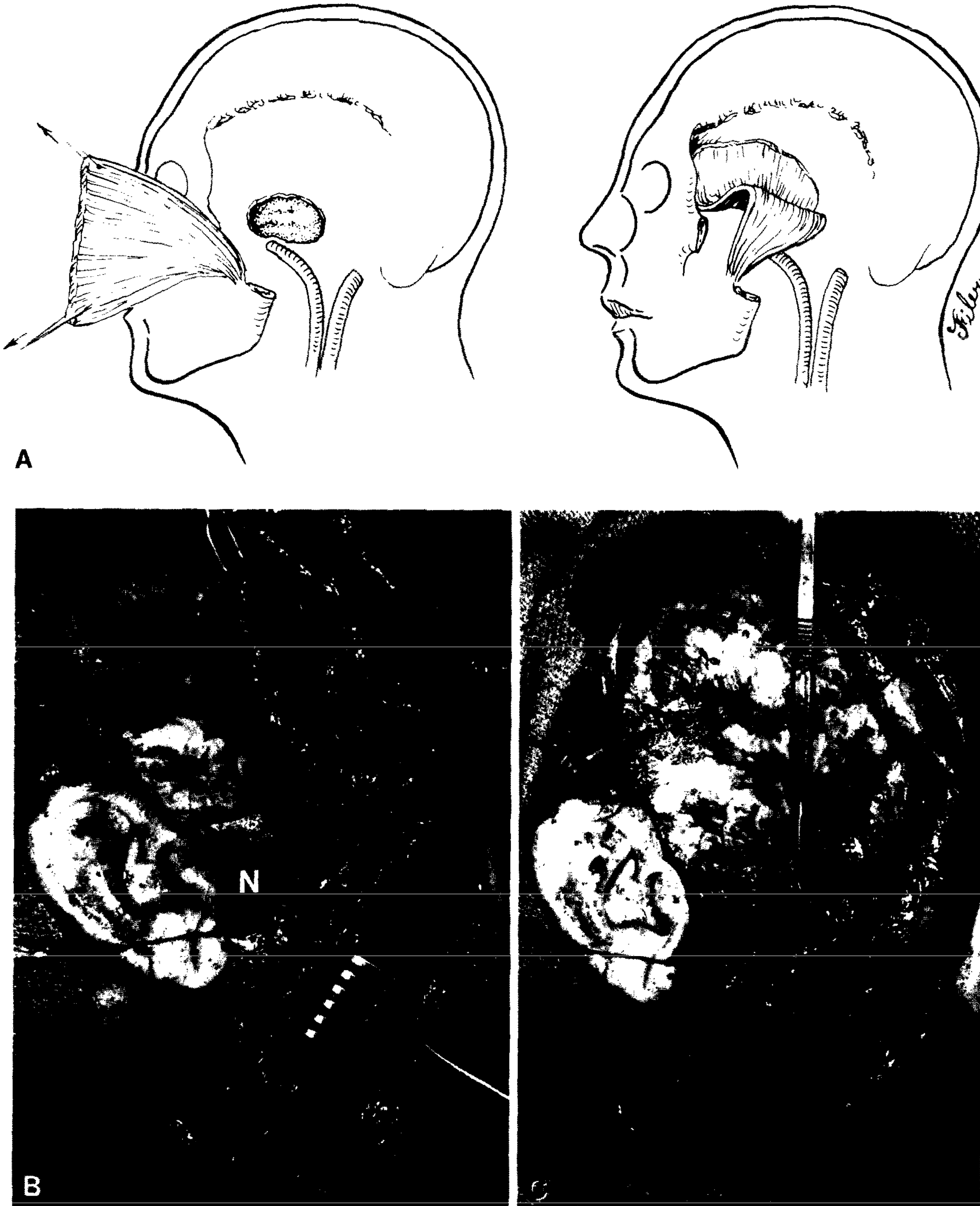


Fig. 2

Figure 2 (A, B and C)—Inferior and medial transposition of the temporalis muscle to reconstruct a small defect of the middle cranial base. N—communication between the nasopharynx and the dural repair overlying the temporal lobe.

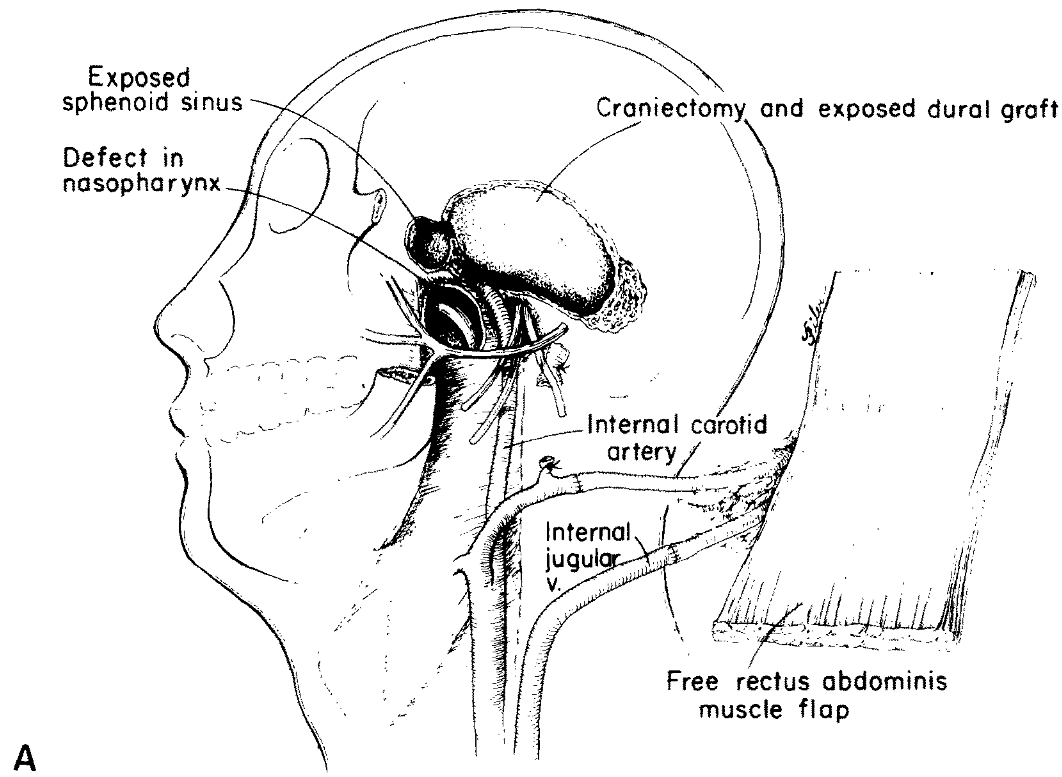


Fig. 3

Figure 3 (A and B)—Diagrammatic representation and operative photograph showing the free rectus abdominis muscle flap being used to separate the nasopharynx from the dural graft overlying the temporal lobe and to obliterate the sphenoid sinus.

initially underwent temporalis muscle transposition developed infection or necrosis of the muscle and were salvaged by free rectus abdominis muscle flap transfer.

An open nasopharynx in direct communication with exposed dura was an indication for reconstruction in 15 patients. Twelve patients had exposed dural grafts in close proximity to the paranasal sinuses. All patients are alive with a follow-up ranging from 2 months to 18 months. There have been no cases of meningitis. Three CSF effusions were contained by the free muscle flaps and resolved following lumbar spinal drainage. Two patients with small CSF leaks required reoperation and repacking of the sphenoid sinus with a small tongue of the muscle flap. There have been no failures of the 11 free muscle flaps, although one required a revision of an interposition vein graft. Since the free rectus abdominis muscle flaps used for reconstruction of the middle and posterior cranial base are completely "buried", the patency of the arterial anastamosis has been monitored continuously using a temporary implantable 20 megaHertz ultrasonic Doppler probe for 7 to 10 days postoperatively (Pinnella *et al.*, 1982).

Discussion

The skull base may be divided into anterior, middle and posterior corresponding to the anterior, middle and posterior cranial fossae. Jackson and Hide (1982) have divided the skull base into anterior and posterior areas, the anterior area corresponding to the anterior cranial fossa and the posterior area being divided into three segments.

The anterior cranial base extends from the anterior midline beneath the anterior cranial fossa to the posterior wall of the orbital cavity. Tumours of the maxilla, maxillary antrum, skin of the midface and parotid may aggressively invade the ethmoid sinuses, the cribriform plate, and the dura and frontal lobes in the anterior cranial fossa. Ketcham *et al.* (1966) described the use of split thickness skin grafts for coverage of the exposed dura in the floor of the anterior cranial fossa following combined facial and intracranial resection of tumours invading the anterior cranial base. This study revealed the extreme importance of adequate coverage of the exposed dura and brain following removal of cranial base tumours. Split thickness skin grafts appeared to be inadequate especially when large dural defects had required fascia lata grafting—almost 50% of patients developed CSF leakage. Ipsilateral and contralateral based forehead flaps and large scalp flaps were then used (Thompson, 1970; Westbury *et al.*, 1975), resulting in a decrease in morbidity. Jackson *et al.* (1984) use an extended glabellar skin flap vascularised by vessels in the supraorbital area to cover the deficient floor of the anterior cranial fossa and Ousterhout and Tessier (1981) have reported a similar technique for closure of large cribriform plate defects using a midline forehead flap. With increasing adoption of the bicoronal scalping incision, a local flap of galea may be separated off the bicoronal scalp flap based on the supratrochlear or supraorbital vessels (Fig. 1 A and B) and this has become a simple and reliable method for reconstructing midline defects in the floor of the anterior cranial fossa (Schramm *et al.*, 1979; Adham *et al.*, 1985).

The temporalis muscle was originally described for coverage of the orbit following orbito-maxillary resections (Bakamjian and Souther, 1975; Holmes and Marshall, 1979). Mobilisation and medial transposition of the muscle is very effective for reconstruction of lateral defects of the anterior skull base. Its reliability, however, becomes questionable for more medially situated defects and some patients have disliked the "hollowed-out" concavity of the temporal fossa after using the temporalis muscle for reconstruction.

With the advent of musculocutaneous flaps, the pectoralis major and extended trapezius musculocutaneous flaps have been advocated for reconstruction of defects of the anterior cranial base. An additional advantage of the musculocutaneous flaps is that they may provide greater protection against bacterial invasion when compared with conventional skin flaps (Ariyan et al, 1980). A further advantage of these flaps is that they may be used in areas that have been previously irradiated and can also tolerate large doses of postoperative irradiation. Sasaki *et al.* (1985) have advocated the use of the pectoralis major musculocutaneous flap for reconstruction of more extensive defects of the anterior cranial base. A possible disadvantage of the pectoralis major flap is that it may have to be placed external to the neck skin in order to reach the level of the supraorbital rim reliably. This therefore requires secondary division of the pedicle and insetting and may create a potential external CSF fistula. Rosen (1985) has recently described the extended trapezius musculocutaneous flap for coverage of the orbito-anterior cranial base region and separation of the dura from the nasopharynx and paranasal sinuses. Provided the skin island is positioned with its distal half beyond the inferior border of the trapezius muscle and the muscle totally mobilised up to the anterior neck, the flap will reliably reach well beyond the supraorbital rim and across the midline. However, the flap requires elevation with the patient in the prone position and repositioning of the patient prior to the resection part of the procedure.

Finally, with increasing reliability of microsurgical free tissue transfer, musculocutaneous flaps may be transferred into this area especially for reconstruction of massive cranio-orbito-maxillary defects. The free latissimus dorsi musculocutaneous flap has been described for closure of large orbitomaxillary defects (Baker, 1984) but we have preferred to use free latissimus dorsi muscle flaps with split thickness skin graft coverage for the two patients in this series with massive defects of the anterior skull base. The greater omentum based on the right gastro-epiploic vessels has also been reported recently as a free tissue transfer for coverage following tumour resection of the anterior skull base (Barrow *et al.*, 1984).

The middle cranial fossa extends from the posterior wall of the orbit to the posterior aspect of the petrous temporal bone and has been divided into anterior and central segments by Jackson and Hide (1982). The internal carotid artery passes from the neck into the petrous temporal bone and enters the middle cranial fossa through the foramen lacerum. The maxillary nerve, the second division of the trigeminal nerve, passes from the middle cranial fossa through the foramen rotundum, and the mandibular nerve, the third division of the trigeminal nerve, passes through the foramen ovale. The facial nerve and acoustic nerve pass through the internal acoustic meatus in the petrous temporal bone. Basal cell carcinoma and squamous cell carcinoma of the skin of the external ear and adjacent scalp and neck skin, carcinomas of the middle ear and parotid tumours may all invade the middle cranial base. Tumours originating more deeply include glomus jugulare tumours, nasopharyngeal carcinomas, clivus chordomas and meningiomas. Traditional methods of reconstructing the defect following temporal bone resection have included large rotation or transposition scalp flaps and the deltopectoral flap (Bakamjian *et al.*, 1971; Westbury, *et al.*, 1975).

The pectoralis major musculocutaneous flap and posterior trapezius musculocutaneous flap have both been advocated for reconstruction following temporal bone resection (McCraw *et al.*, 1979; Ariyan *et al.*, 1981). Vascularised muscle has proved efficacious in sealing the dura against CSF leaks and the skin paddle will withstand postoperative irradiation. Tumours originating more deeply such as glomus tumours, nasopharyngeal carcinomas, clivus chordomas and extra-cranial meningiomas may now be adequately exposed by an infratemporal fossa approach (Sekhar *et al.*, 1986). For small laterally situated defects, the temporalis muscle, which has been totally elevated during the operative approach, may be transposed inferiorly and medially to cover the dural graft overlying the temporal lobe (Fig. 2 A, B and C). However, with medially situated tumours and especially those patients in whom resection results in a communication between the nasopharynx and the dural repair, transposition of the temporalis muscle or the pectoralis major musculocutaneous flap may be unreliable. In these circumstances the free rectus abdominis muscle has been used to restore continuity to the posterior and lateral pharyngeal walls and so separate the open nasopharynx from the exposed temporal dura. Tongues of muscle may be used to obliterate the sphenoid sinus or drape around a saphenous vein graft reconstruction of the internal carotid artery. The disadvantage of this method is that microsurgical expertise is required and monitoring of these completely invisible free flaps is difficult.

The posterior skull base or posterior segment described by Jackson and Hide (1982) extends from the posterior aspect of the petrous temporal bone to the midline of the posterior skull. The glossopharyngeal nerve, vagus nerve and spinal accessory nerve and the internal jugular vein pass from the posterior cranial fossa through the jugular foramen. The hypoglossal nerve exits from the posterior cranial fossa through a separate canal, the anterior condylar canal. Glomus tumours and schwannomas are the most common tumours involving the posterior cranial base. These tumours may be approached through the transtemporal approach (Fisch *et al.*, 1984) and resection usually requires removal of bone around the carotid artery and the sigmoid sinus together with a retro-mastoid craniectomy. Small defects of the posterior skull base with exposed dural repairs or dural grafts of the posterior fossa may be protected by inferior transposition of the temporalis muscle or superior transposition of the sterno-mastoid muscle based on its superior vascular supply from the occipital artery (Jackson and Hide, 1982). The trapezius musculocutaneous flap is especially indicated for laterally situated defects in this posterior skull base territory because of its close proximity and because the spinal accessory nerve is frequently sacrificed as part of the tumour resection. Finally, for reconstruction of large defects of the posterior cranial base extending into the middle cranial base, free rectus abdominis muscle flaps may occasionally be required.

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