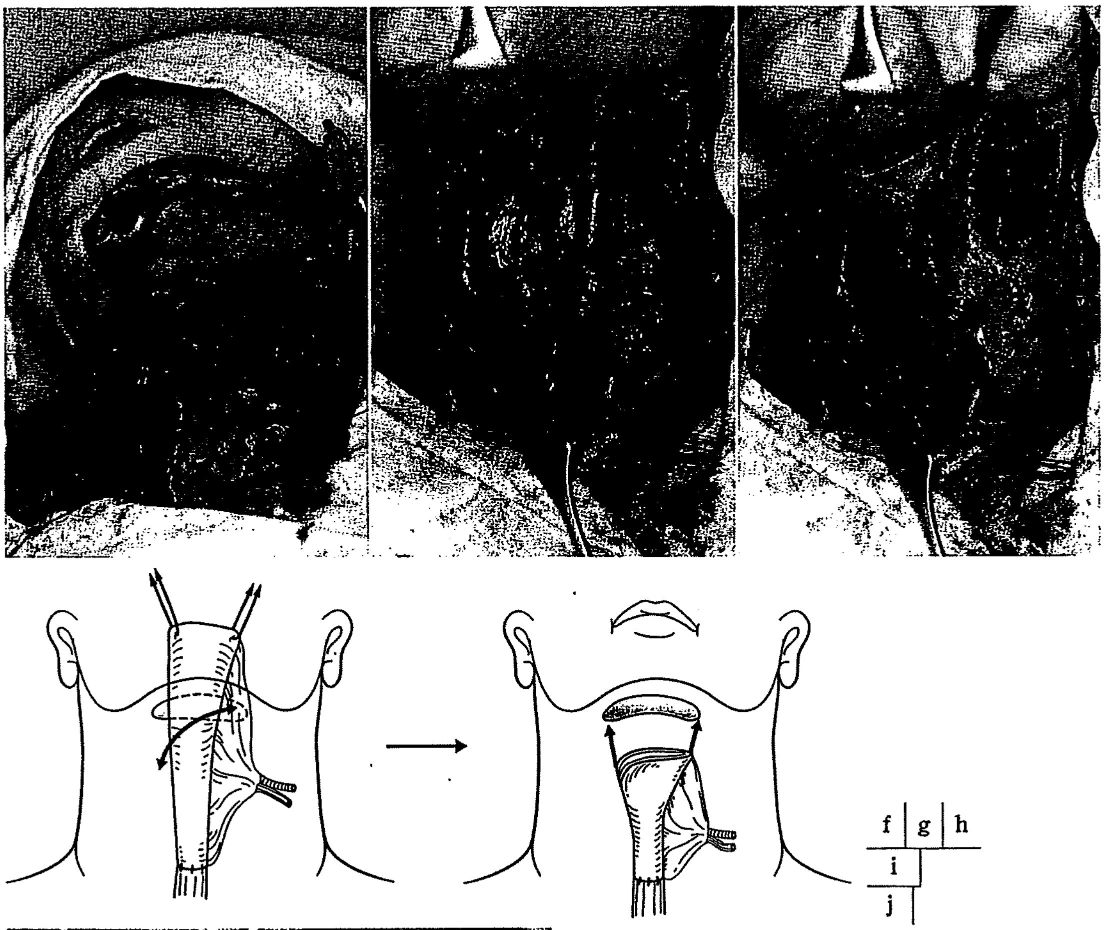


(f) 余剰な空腸片の腸間膜を切離した状態
(g) 移植空腸は阻血状態で欠損長の半分ほどとなっている。
(h) 伸展した状態で空腸の咽頭側吻合を行う。
(i) 咽頭側の口径と合わせるため，空腸には斜め切開を加える。通常の咽喉食摘後の欠損であれば，この切開で十分対応できる。
(j) 咽頭側の後壁縫合が終了した状態
支持糸により十分な視野を確保して縫合を行う。

図3

な縫合固定が必要である点である。特に，粘膜断端面が内腔側に向くよう，つまり invert するように正確に縫うことが瘻孔形成を防止する。われわれは 4-0 vicryl を使用し，前壁では Gambee 縫合を多用している。

さらに実際の縫合では，血管吻合時と同じように切断端両サイドに支持糸をかけ内腔がよく見える状況を作り出し，正確に粘膜・漿膜面を確認しながら糸をかけるようにしている。

血管閉塞に関わる因子として，血管柄の緊張や kinking などが挙げられるが，われわれ

(a) 血管吻合終了後，血流再開前の状態　(b) 血流再開後も移植空腸に弛みはなく，直線状の食道が再建されている。

図4　血流再開前後の状態

(a) 側面　(b) 斜位

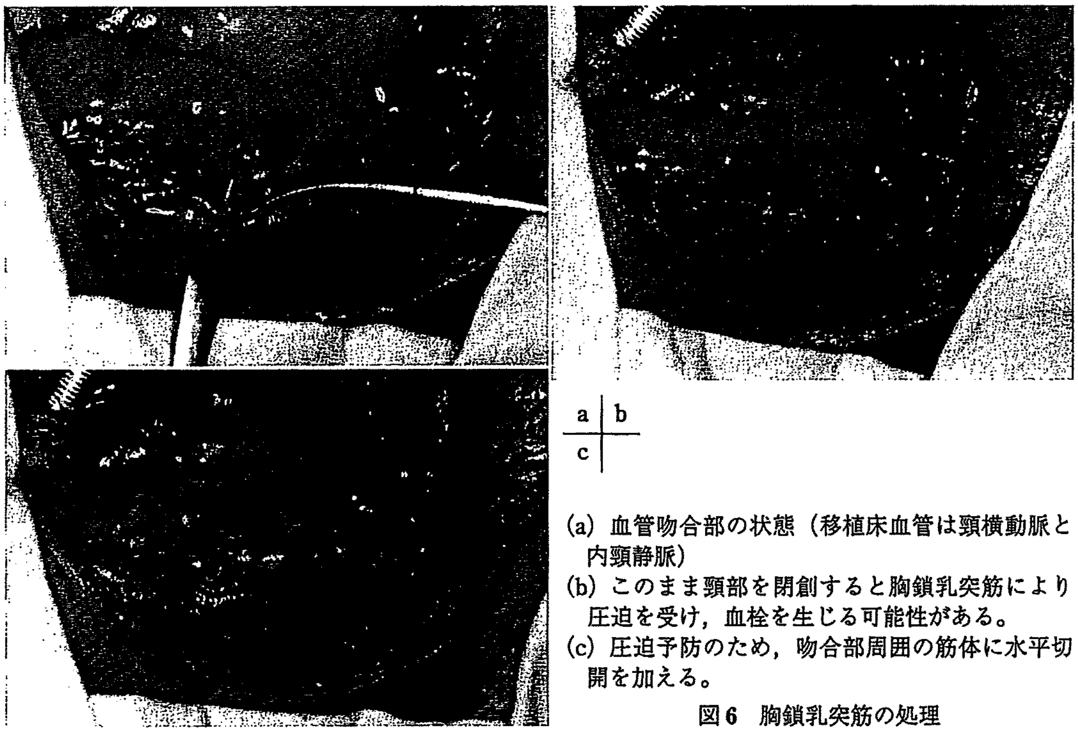
図5　術後透視像

術後の透視像でも空腸には弛みがなく，良好な造影剤の通過を認める。

の術式では，最初のトリミング（位置決め）の段階で十分な配慮を行っている。ただ，胸鎖乳突筋が温存されている症例では，頸部皮膚の閉鎖によりちょうど筋体が血管吻合部を圧迫することがある。特に，上甲状腺動脈への端々吻合と内頸静脈への端側吻合を施行した場合には，その危険性が高いので，筋体内側縁に切開を加えておく（図6）。

ドレーンの固定場所も吻合血管に影響を与えないよう注意が必要である。特に，血管吻合側では頸部外下側にドレーンを置き，体位交換などでずれないように糸でゆるく留めておく。副神経や頸神経が温存されている時は，その下をかいくぐるようにドレーンを留置しておく。

Free flap 時の血管閉塞は，これまで著者が



a | b
c

(a) 血管吻合部の状態（移植床血管は頸横動脈と内頸静脈）
(b) このまま頸部を閉創すると胸鎖乳突筋により圧迫を受け，血栓を生じる可能性がある。
(c) 圧迫予防のため，吻合部周囲の筋体に水平切開を加える。

図6　胸鎖乳突筋の処理

報告してきたように術後3日以内に発生することが80％と大多数の症例を占める[12)]。しかし，術後1週以上経っても瘻孔などによる感染・炎症から二次的に閉塞することもあり得るので，血管吻合部周囲の局所感染には十分な注意が必要である。

なお，術式で説明したようにわれわれは採取空腸にかなりの緊張をかけた状態で移植しているが，阻血状態で丁寧・確実な吻合を行うことにより瘻孔形成は極めてまれである。正確なデータはないが，緊張をかけた吻合を行うことにより可及的に直線状の食道が再建され，嚥下機能も良好である印象を受けている。

なお，食道側の吻合に関しては，簡便な手段として自動吻合器を用いる方法もあるが，手縫いに比べ狭窄発生率が高いことを経験しており，諸家によってもすでに報告されている[13)14)]。

まとめ

咽喉食摘後の下咽頭・頸部食道の再建には遊離空腸移植術が，機能的にも安全性・確実性の面でも現時点で最も信頼できる再建法であることは論を俟たない。

本稿では，代表的な適応である咽喉食摘後の欠損に対する，われわれの遊離空腸移植術の術式および合併症回避のための注意点について述べた。

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頭頸部癌切除後の再建における移植床血管選択のポイント

中塚貴志*　横川秀樹**　佐藤智也**

Key words：移植床血管　頭頸部再建　遊離組織移植

はじめに

頭頸部癌切除後の再建における血管柄付き遊離組織移植術（以下，free flap）の有用性はすでに衆目の一致するところである。本術式の導入により，形態的・機能的に複雑な要素を有するこの領域の再建成績が飛躍的に向上した。

そして頭頸部再建においてfree flapを成功させるためには，皮弁の選択，デザイン，挙上手技はもとより，血管吻合に適した移植床血管を選択することが最も肝要である。

本項では，頭頸部移植床血管の選択のポイントと問題点につき述べる。

I 頭頸部の血管解剖

頭頸部には他部位に比べて豊富な血管系が存在するため，解剖学的にはfree flapに適した血管が比較的容易に選択できる。

上顎や頭蓋底など顔面上部の再建には，浅側頭動静脈，顔面動静脈などが選択されることが多い。口腔，中咽頭，下咽頭などの再建には，動脈は外頸動脈の枝である上甲状腺動脈，顔面動脈，舌動脈，頸横動脈が選択肢となり，静脈は外頸静脈，内頸静脈本幹もしくはその枝（総顔面静脈）などが候補となる（図1）。

*埼玉医科大学形成外科
**埼玉医科大学国際医療センター形成外科

II 頭頸部の血管選択の要点

前述のように解剖学的には血管吻合可能な血管は比較的多数存在し，特に癌切除後の即時再建例では多くの場合，頸部郭清に伴いこれらの血管がすでに剝離露出されていることが多い（図2）。その中で吻合に適した健常な血管とは一般に下記の要件を満たすものである。

動脈では，内膜の剝離・変性が少なく，なによりも断端からの拍出量が十分であるこ

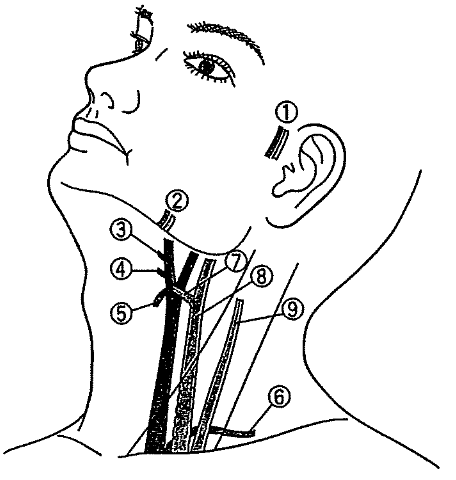

図1　頭頸部の主な移植床血管
①浅側頭動静脈，②顔面動静脈，③顔面動脈，④舌動脈，⑤上甲状腺動脈，⑥浅頸動脈，⑦(総) 顔面静脈，⑧内頸静脈，⑨外頸静脈

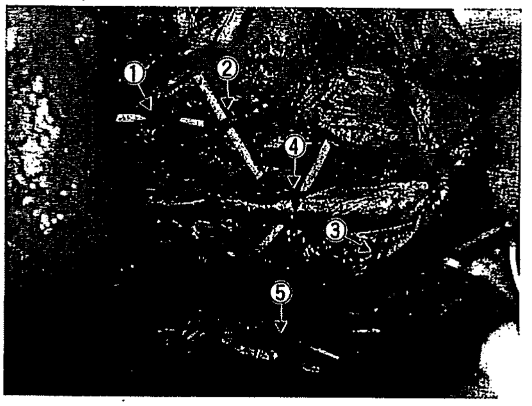

図 2　頸部郭清後に剝離露出された血管
①舌動脈，②上甲状腺動脈，③浅頸動脈，④内頸静脈，⑤外頸静脈

図 3　外頸動脈と内頸静脈への端側吻合
①外頸動脈への端側吻合，②内頸静脈への端側吻合

と，そして全体的な硬化変性を認めないことである。ただし，拍出量が不良な時は，血管の剝離操作により攣縮を起こしている場合や，血圧の低下が原因であることもある。前者の場合には 10 倍希釈のパパベリン塩酸塩溶液を局所散布すれば次第に回復する。後者の場合，一般に術中の収縮期血圧が 100 mg 以下にならないよう麻酔科医に血圧コントロールを依頼しておく。

一方，静脈では，硬化変性が少なく，吻合に際し圧迫や捻じれを生じにくい部位の血管を選ぶ。なお，静脈も剝離操作により攣縮を来たすことがあるが，これに対しては有効な攣縮防止薬はないので，生理食塩水ガーゼなどで乾燥を防ぎつつ自然な回復を待つのがよい。

なお，動静脈ともに端々吻合を行う場合には，皮弁の栄養血管と口径差ができるだけ少ないものを選択する。口径差が 1.5〜2 倍程度までであれば，細い方の血管内腔を鑷子で愛護的に拡張させることで対応可能であるが，2 倍以上の場合には細い方の血管に fish-mouth incision や斜め切開を加えることにより口径差に対処する。また，口径の細い側から太い側に血流が流れるように移植床の血管を選択する方が血栓形成防止の観点からは安全と考えられる。

一方，端側吻合の場合には，動脈では外頸動脈本幹[1]が，静脈では内頸静脈[2]が選択される。ただし前者では，全身的な動脈硬化が強く外頸動脈自体も硬く蛇行しており外観から粥状プラークが透見できるような場合には，側孔を開ける際に内膜剝離が生じやすく不適と考えられる。

これに対し，後者の内頸静脈への端側吻合は比較的多く用いられている。その理由は，内頸静脈のどこにでも随意に吻合できる，内頸静脈には絶えず胸腔内からの陰圧が作用するので血栓を生じにくいと考えられる，端側吻合なので口径差を考慮する必要がないなどが挙げられる。著者は頭頸部再建においては，1988 年から内頸静脈への端側吻合を始め，以来好んで用いており，安定した成績を得ている[2]（図 3）。

すでに著者が報告した free flap による頭頸部再建 2,372 例の吻合血管のうち，動脈は，上甲状腺動脈が最も多く使用されており，浅頸（頸横）動脈，顔面動脈と続いているが，顔面動脈でやや血栓形成率が高いものの，吻合に使用した動脈間に統計的有意差はなかった[3]（表）。なお，上甲状腺動脈が多用されている理由として，解剖学的変異が少ないことはもとより，上頸部の血管吻合に適した位置

表　移植床血管別の血栓形成率

	血栓形成率	症例数
＊動脈		
上甲状腺動脈	1.8 %	(23/1306)
浅頸動脈	1.8 %	(8/454)
顔面動脈	3.2 %	(11/344)
舌動脈	0.9 %	(1/106)
浅側頭動脈	1.4 %	(1/69)
＊静脈		
内頸静脈	2.0 %	(17/865)
顔面静脈	2.0 %	(14/717)
外頸静脈	2.7 %	(14/519)
上甲状腺静脈	3.5 %	(3/85)
浅側頭静脈	1.5 %	(1/66)

(Nakatsuka T, et al : Analytic review of 2372 free flap transfers for head and neck reconstruction following cancer resection. J Reconstr Microsurg 13 : 363−368, 2003 より引用改変)

に存在すること，外頸動脈本幹からの距離が短く安定した良好な拍出を得やすいことなどが挙げられる。

静脈に関しては，内頸静脈（端側吻合），顔面静脈，外頸静脈の順に多用しているが，やはり血栓形成率に関し統計上の有意差は認められなかった。

Ⅲ 頭頸部に適した移植床血管がない場合

1. 頸部以外に移植床血管を求める

頭頸部癌治療後の再建の場合には，術前の放射線照射や既往の手術などにより患側術創部に著しい瘢痕化，線維化を認め血管の剥離・露出が極めて困難であったり，以前の頸部郭清手術などにより上述したような吻合に適した血管が存在しない場合など，移植床血管の選択に難渋する事態も起こり得る。もちろん，対側の頸部に健常な血管が残存していれば，血管柄の長い皮弁を用いることにより対応可能であるが，それも難しい場合には，頭頸部以外に移植床血管を求めなければならない。

一般に頭頸部以外の領域で候補となる血管としては，内胸動静脈，胸肩峰動静脈があり，静脈のみの場合は橈側皮静脈（cephalic vein）を剥離し反転して利用することも可能である。

内胸動静脈は乳房再建などに多用されているが，通常第 2，3 肋骨を切除し動静脈を剥離後反転して吻合に利用する。この血管は口径や枝分かれに左右差があり，一般に右側では枝分かれが少なく口径も太いとされている[4]。特に，静脈は左側が細く吻合に適さないことがある。血管剥離時の注意点としては胸膜を損傷しないようにすることである。

胸肩峰動静脈は，比較的口径の太い本幹で吻合しようとすると吻合面が垂直となりやすくやや深部になるため手技的に難しい面もある。また，胸肩峰静脈が細いため，橈側皮静脈を移植床静脈とせざるを得ないことが多い[5]。さらに本動静脈を吻合に利用すると，その側の大胸筋皮弁が使用できなくなる欠点がある。

橈側皮静脈は，前胸部から上腕にかけて剥離すれば顎下部まで到達させることが可能であり[5]，血管柄の短い皮弁による頭頸部再建にも十分対応できる。

2. Arteriovenous loop を作製する

欠損部近傍に吻合に適した移植床血管がない場合，静脈移植や静脈の有茎移動により動静脈シャントを作製した後，そのループの頂点を切断し，遊離組織の栄養動静脈と端々吻合を行うもので，Corlett loop，arteriovenous fistula とも呼ばれている。

これまで主に下肢の再建で多くの報告があるが，シャント作製後すぐに皮弁の血管と吻合する方法（即時吻合）と時間（2～4 週間）をおいてから改めて移植を行う方法（二期吻合）がある。しかし，血栓形成率や閉塞率は 3～50 % と報告によりさまざまであり，特に二期的吻合法ではシャントの閉塞率が高いとの報告が多い[6,7]。

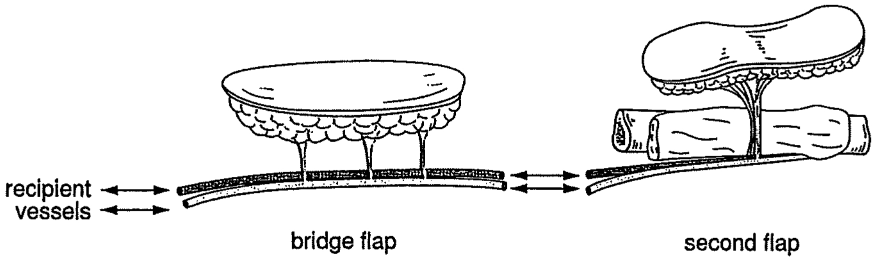

図4　Bridge flap のシェーマ

頭頸部では，橈側皮静脈を長く剝離し有茎で移動し頸部の動脈と吻合する，大伏在静脈を頸部の動静脈と吻合するなどの方法があるが[8]，あまりまとまった報告は見られない。

Ⅳ 複数の皮弁を同時に移植する場合

頭頸部の欠損部が広範囲であったり，下顎の再建などで一つの骨皮弁だけでは十分な再建ができない場合など，複数の皮弁移植が必要とされることがある。そのような場合，移植する free flap の数に相応するだけの健全な移植床動静脈の対が存在することは必ずしも期待できない。

そのような場合に，1対の移植床血管を利用して2つの free flap を可能にする方法として，flow through タイプの栄養動静脈を有する皮弁（前腕皮弁，前外側大腿皮弁，腓骨皮弁など）をまず頸部の移植床血管と吻合して移植した後，その皮弁の栄養血管の末梢にもう1つの皮弁の栄養血管を吻合する方法がある（図4）。このように間置される皮弁は bridge flap，chain flap などとも呼ばれる。

著者らはすでに1992年に本法を応用した症例を報告している[9]が，基部での血管吻合が閉塞すれば複数の移植組織が全壊死になる危険性はあるものの，経験を積んだチームで行えば有用性は高いと思われる。

上記以外では，光嶋らが報告しているキメラ形皮弁移植もある[10]が，著者らは行っていない。

Ⅴ 考　察

1. 頭頸部再建で皮弁生着に関連する因子

これまで諸家により free flap を用いた頭頸部再建における危険因子の報告がなされている。

Mulholland ら[11]は，頭頸部再建の放射線照射例226例と非照射例108例を比較し，Aitasalo ら[12]は，同じく照射例77例と非照射例11例で比較し，皮弁壊死率に有意差がなかったことを報告している。

一方 Schusterman ら[13]は，308例の頭頸部再建例を検討し，皮弁壊死につながる要因は，既往手術歴と静脈移植の使用であったとしている。また，Nahabedian ら[14]は102例の遡及的調査で吻合部閉塞は，arteriovenous loop 作製例や喫煙例に高率に生じ，吻合に利用した移植床血管や患者の年齢，術前照射の有無には関係ないと報告している。

われわれの経験でも，術前の放射線照射歴があるだけでは free flap の禁忌とはならず，候補となる移植床血管を剝離露出させて，血管自体の柔軟さ拍動の良さを触診・視診で確かめ，内膜の肥厚や剝離がないことなどを手術用顕微鏡下に確認したうえで，最終的に吻合の適否を決定している。それゆえに，使用した移植床血管による閉塞率に統計的な有意差は生じないのではないかと考えられる。

2. 内頸静脈系と外頸静脈系の比較

頭頸部の再建では，以前より移植床静脈として外頸静脈系と内頸静脈系が用いられてきたが，近年では内頸静脈本幹への端側吻合を施行することが圧倒的に多くなっている。多数例の解析では先述したように内頸，外頸静脈の使用症例間において血管閉塞率に関し統計的有意差はないものの，著者らは外頸静脈への吻合は第 1 選択とはしないようにしている。

その理由は，外頸静脈は通常頸部郭清時に切断され断端が長く残されているので，吻合後に捻じれや kinking を生じやすい，胸鎖乳突筋上を走行するので術後に外部からの圧迫を受けやすい，端々吻合するには多くの場合移植組織の静脈との口径差が大きいなど，血栓形成に結びつきやすいリスク要因を有しているためである。

Chalian ら[15]は，頭頸部再建例で，外頸静脈を吻合に使用した 65 例と内頸静脈およびその枝に吻合した 86 例を比較検討し，前者では 5 例に静脈血栓が生じ，後者には血栓が生じなかったことより，内頸静脈系を第 1 選択とすべきであるとしている。さらに Fukuiwa ら[16]も 102 例の頭頸部再建例を調査し，外頸静脈系への吻合例の方が有意に高率に静脈血栓による皮弁壊死を生じていたと報告している。

ただ，内頸静脈に関しては，頸部郭清後に内頸静脈血栓を生じる例があるとの指摘も近年なされている。その発生率は 14〜25 % とするもの[17][18]もあれば，血栓はまったく生じなかったとするもの[19][20]までさまざまである。著者らの経験では，基本的に内頸静脈に対する手術操作の適否が血栓形成に大きく影響していると考えている。具体的には，手術中に血管壁に損傷が加わる，本幹近くで枝を結紮したために本幹にくびれや捻じれが生じる，頸部郭清により周囲組織から完全に剥離され内頸静脈本幹が容易に回転しやすくなっており，また外力を受けやすくなっていることなどが原因となり，血栓形成につながる可能性が高いと思われる。これらの点に留意しつつ，内頸静脈の外膜を顕微鏡下に剥離しできるだけ一定の内径を保つようにした状態で血管吻合を行うようにすれば問題はないと考えている。

3. 移植床血管の選択のバリエーション

上述のように内頸静脈への端側吻合が最近では最も多用されているが，頸部郭清の結果，内頸静脈が結紮切断されている症例にも遭遇することがある。さらに外頸静脈系も利用不可能な場合，この内頸静脈の断端に端側吻合するかどうか迷うことがある。著者は胸腔内の陰圧が血管断端に十分伝わっている状況であれば，吻合に利用することも最後の選択肢としてはあり得ると考えている。Graham ら[21]は，根本的頸部郭清後の内頸静脈切断端に皮弁の栄養静脈を端側吻合した 8 症例を報告し，全例トラブルもなく生着し，有用な選択肢となり得るとしている。

また，別の観点から興味ある論文としては，Neligan ら[22]の逆行性の動脈吻合による臨床例の報告がある。上甲状腺動脈を吻合に利用する場合，多くの場合上方に反転させなければならないが，それにより生じる血管の捻じれ，kinking を避けるために，彼らは上甲状腺動脈の末梢側に皮弁の栄養血管を吻合した。口腔底癌症例などの再建 16 例に本術式を施行し，内 2 例では逆行性の動脈拍出が不良なため外頸動脈への端側吻合に切り替えているが，ほかの 14 例では皮弁の生着に問題はなかったとしている。この際同時に，吻合に用いる上甲状腺動脈末梢側にカニュレーションを行い動脈圧も測定している。その結果，末梢側の動脈圧は結紮切断直後は体血圧の 60 % 程度に低下しているが，皮弁の生着から考えて時間とともに平均血圧に近づくであろうと類推している。確かに身体各部位で逆行性の

皮弁が生着することから判断すれば，このような逆行性の動脈吻合も場合によっては選択肢の一つとなり得ると考えられる。

まとめ

遊離組織移植による頭頸部再建は今や安全で確立した術式として広く認知されている。しかし，その確実な成功のためにはいかに健全な移植床血管を同定し確保するかが鍵を握っている。

本稿では，著者らの経験および文献的考察に基づき，頸部移植床血管の選択の要点，さらに頸部に移植床血管を求められない場合の対処法，特殊な移植床血管の利用法などにつき述べた。

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ABSTRACT

Proper Selection of Recipient Vessels for Free-Tissue Transfers in Head and Neck Reconstruction

*Takashi Nakatsuka, MD *, Hideki Yokogawa, MD ** and Tomoya Satou, MD ***

Microvascular free tissue transfer in head and neck reconstruction is commonly used to obtain good functional and esthetic results. However, for free tissue transfer to be successful, proper selection of recipient vessels is one of the most essential factors. The healthy recipient artery which has good pulsation without any evident intimal degeneration should be selected for microvascular anastomosis. In our experience of 2372 free tissue transfers for head and neck reconstruction, the superior thyroid artery is the most commonly used recipient artery followed by the superficial cervical and facial artery. As for the recipient vein, recently we prefer to use an end-to-side anastomosis to the internal jugular vein rather than an end-to-end anastomosis to the external jugular vein. However, there was no significant statistical difference in the thrombosis rate between the commonly used recipient vessels in our series.

If there are no available recipient vessels in the neck due to previous surgery or chemoradiation, the internal mammary vessels, thoracoacromial vessels, and cephalic vein represent reliable alternatives.

* *Department of Plastic, Reconstructive and Aesthetic Surgery, Saitama Medical University, Saitama 350–0495*

** *Department of Plastic and Reconstructive Surgery, Saitama International Medical Center, Saitama 350–1298*

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Long-term outcome following radical temporal bone resection for lateral skull base malignancies: a neurosurgical perspective

NOBUTAKA KAWAHARA, M.D., PH.D.,[1] TOMIO SASAKI, M.D., PH.D.,[2] TAKAHIRO ASAKAGE, M.D., PH.D.,[3] KAZUNARI NAKAO, M.D., PH.D.,[3] MASASHI SUGASAWA, M.D., PH.D.,[4] HIROTAKA ASATO, M.D., PH.D.,[5] ISAO KOSHIMA, M.D., PH.D.,[6] AND NOBUHITO SAITO, M.D., PH.D.[1]

Departments of [1]Neurosurgery, [3]Otorhinolaryngology, and [6]Plastic Surgery, Graduate School of Medicine, University of Tokyo, Tokyo; [4]Department of Otorhinolaryngology and Head and Neck Surgery, Faculty of Medicine, Saitama Medical University, Saitama; [5]Department of Plastic Surgery, Dokkyo Medical University, Tochigi; and [2]Department of Neurosurgery, Graduate School of Medical Science, Kyusyu University, Fukuoka, Japan

Object. Primary temporal bone malignancy is a rare form of tumor for which the therapeutic strategy remains controversial. In this study, the authors reviewed their experience with radical temporal bone resection (TBR) of such lesions and analyzed the long-term results to provide treatment recommendations.

Methods. Between 1994 and 2006, 17 patients (10 men and 7 women) underwent total or subtotal TBR for primary temporal bone malignancies. Tumors were graded according to the University of Pittsburgh system. The effects of surgical margins and tumor extensions on patient survival were analyzed using the Kaplan–Meier method.

Results. All tumors, except 1, were graded T4 (most advanced). Subtotal TBR was performed in 14 patients, and total TBR was performed in 3. The surgical margin was tumor negative in 10 patients and tumor positive in 7. For large tumors extending into the infratemporal fossa or encroaching on the jugular foramen, orbitozygomatic (3 patients) and posterior transjugular (4 patients) approaches were combined with the standard approach, and en bloc resection with a negative margin was achieved in all cases but 1. The follow-up time ranged from 0.3–11.6 years (mean 3.3 years). The 5-year recurrence-free and disease-specific survival rates were 67.5 and 60.1%, respectively. When a negative surgical margin was achieved, the survival rates improved to 100 and 89%, respectively.

Conclusions. The neurosurgical skull base technique could improve the probability of en bloc resection with a tumor-free margin for extensive temporal bone malignancies, which would cure a subset of patients. The active participation of neurosurgeons would improve patient care in this field. *(DOI: 10.3171/JNS/2008/108/3/0501)*

KEY WORDS • long-term outcome • malignancy • prognostic factor • skull base surgery • temporal bone resection

PRIMARY malignancies involving the lateral skull base are rare, with an estimated annual incidence of 6 cases per million persons.[30,38] Consequently, therapeutic strategies remain controversial, particularly for advanced tumors.[30] Historically, these lesions were considered unresectable due to intricate neurovascular structures within the temporal bone. In 1954, the pioneering work of Parsons and Lewis[27] introduced the concept of subtotal en bloc resection of the temporal bone. In their initial series of 100 cases, the 5-year cure rate remained poor (27%) and the surgical mortality rate was relatively high (5–10%).[20] Therefore, Kinney and Wood[16] advocated step-by-step piecemeal gross-total resection combined with postoperative radiation therapy, which reduced the surgical mortality rate to 3.3% and produced comparable results for extensive tumors. In 1994, Prasad and Janecka[30] systematically analyzed 26 articles and identified a beneficial trend of subtotal resection of temporal bone tumors beyond the external ear canal; however, they could not determine whether en bloc resection generated better results than piecemeal resection.

Despite these controversies, substantial progress in skull base surgery has been made in the past decade, and most authors of recent literature agree that en bloc resection with tumor-free margins is the optimum treatment.[21,24,26,29,38] For the most advanced tumors, however, optimum resection

Abbreviations used in this paper: CN = cranial nerve; CT = computed tomography; DSS = disease-specific survival; EAC = external auditory canal; ICA = internal carotid artery; IMRT = intensity-modulated radiation therapy; MR = magnetic resonance; RFS = recurrence-free survival; SCC = squamous cell carcinoma; TBR = temporal bone resection.

remains technically difficult, and the overall patient survival rate remains poor.

Given that the lateral skull base is a complex region, radical surgery for malignant tumors in this area often requires the participation of surgeons from several disciplines, such as head and neck surgery, neurosurgery, and plastic surgery, to obtain the best results.[5,9] In particular, the role of the neurosurgeon is important in achieving en bloc resection with a tumor-free margin, as medial structures can be directly approached via craniotomy while leaving the whole lateral temporal bone in situ.

At our institution, a multidisciplinary team performed 17 radical TBRs for advanced lateral skull base malignancies between 1994 and 2006. During this period, surgical modifications and cooperation among surgeons improved the probability of successful radical resection. The objectives in the current study were to analyze data in patients who had undergone radical TBR, to describe the surgical technique used with emphasis on its neurosurgical aspects, and to offer treatment recommendations based on these results.

Clinical Material and Methods

Patient Population

We retrospectively reviewed the records of 17 patients with lateral skull base malignancies who had undergone total or subtotal TBR between 1994 and 2006 (Table 1). The group consisted of 10 male and 7 female patients, with an age range of 9–73 years (mean 53 years) at the time of the operation. The most frequent histological subtype was SCC (9 patients), followed by adenoid cystic carcinoma (4 patients), carcinoma ex pleomorphic adenoma (1 patient), adenocarcinoma (1 patient), Ewing sarcoma (1 patient), and myoepithelial carcinoma (1 patient). The origin of the tumor was the EAC in 7 patients, the middle ear in 4, the parotid gland in 5, and the temporal bone in 1. Eight patients had local recurrence of tumors that had been treated at other hospitals by using local surgery, mostly combined with radiotherapy. All patients except 1 (Case 10; lost to follow-up after 2.9 years) were followed up until death or the end of the study, with follow-up periods ranging from 0.3–11.6 years (mean 3.3 years).

Preoperative Imaging

Magnetic resonance imaging and x-ray CT scanning with contrast enhancement were performed to delineate tumor extension and bone destruction. Carotid artery angiography was also performed to evaluate tumor stain, jugular vein dominancy, and collateral flow through the circle of Willis. In selected cases in which the tumor extended to the carotid canal, a balloon occlusion test was performed to assess the risk of ICA sacrifice. If the patients clinically tolerated 20 minutes of ICA occlusion and the hemodynamic study using single-photon emission CT with technetium-99m hexamethylpropyleneamine oxime showed no side difference, we concluded that the ICA sacrifice was safe. In other patients, revascularization with a radial artery graft was planned in case of injury or sacrifice. In the current series, however, the ICA was not directly invaded by the tumor and was successfully preserved in all cases. To exclude systemic metastasis, whole-body CT scanning or fluorine-18–labeled fluorodeoxyglucose–positron emission tomography was conducted. When these imaging studies disclosed distant metastasis, the indication for radical tumor resection was suspended.

Tumor Grading

No uniform tumor grading has been established for temporal bone malignancy, so we used the grading system established by the University of Pittsburgh (Table 2), which was originally proposed for SCCs of the EAC and based on preoperative CT.[1,13] In the current study, grading was determined using preoperative MR imaging to delineate tumor extensions more precisely.

Surgical Technique

Patients underwent either subtotal or total TBR, depending on the location and extension of each tumor. Stereotactic navigation systems are now increasingly used in cases of deep-seated brain lesions and can also be useful for TBRs; however, we did not use the navigation system, because the navigation frame often limits access to the tumor margin from various angles and because anatomical orientation is easily achieved using normal osseous landmarks outside the resection line.

Subtotal TBR. After lumbar drainage, the patient was placed supine. A large C-shaped skin incision was made to expose the frontotemporosuboccipital bone, while leaving the tumor-invaded skin and soft tissue in situ. The lower CNs, ICA, and internal jugular vein were secured in the neck. The ramus of the mandible was cut in cases of tumors involving the temporomandibular joint and infratemporal fossa, and a large frontotemporosuboccipital craniotomy was preformed. When dural invasion was suspected, the involved dura mater was resected and left attached to the tumor, and the defect was repaired with the free fascia lata graft. After sufficient lumbar drainage, the carotid canal was first identified in the middle fossa, and bone drilling was extended laterally to the infratemporal fossa while exposing the petrous ICA. Medial bone drilling was initiated from the carotid canal posteriorly, traversing the cochlea and internal auditory canal to the posterior fossa. Thereafter, the sigmoid sinus was dissected from the temporal bone without mastoidectomy, and the bone drilling line from the middle fossa was continued laterally to the jugular foramen. The remaining osseous septum was cut with a chisel, and the tumor was removed en bloc. If tumor remnants were suspected, additional bone or soft-tissue removal was performed. The open internal auditory canal was packed with a fascia plug, and the dead space was filled with free tissue transfer of the rectus abdominis musculocutaneous flap.

After our initial experiences with the first 8 cases, this standard subtotal TBR technique was modified to achieve complete en bloc tumor resection. For tumors extending to the jugular foramen, the foramen was opened posteriorly via the extradural route without touching the lateral wall (posterior transjugular approach), and the jugular bulb and vein were dissected from the osseous canal, leaving adjacent tumor attached to the main tumor mass (3 cases). In another patient (Case 14) in whom the tumor directly invaded the wall of the sigmoid sinus and jugular bulb, the former was ligated and the latter was directly opened intra-

TABLE 1

*Characteristics of 17 patients who underwent radical TBR for skull base malignancies**

Case No.	Age (yrs), Sex	Tumor Origin	Patho-physiology	Tumor Grade†	Previous Local Surgery	XRT Pre-/Postop (Gy)	Periop Chemotherapy	Type of Resection	Tumor-Free Surgical Margin	Sacrificed CN	Other Complications	FU (yrs)	Outcome
1	54, F	EAC	ACC	T4	yes	50/45	—	subtotal	positive	VIII	meningitis, encephalitis	1.1	DOD
2	9, M	TB	Ewing	T4	no	—/40	VCR/IFO/VP-16/CPM/DXR	total	positive	VII, VIII	none	1.3	DOD
3	64, M	ME	SCC	T4	yes	60/—	—	subtotal	negative	VII, VIII	none	5.4	DOC (pneumonia)
4	45, M	PG	adeno	T4	no	—/60	CDDP/THP	total	positive	V3, VII, VIII	none	1.8	DOD
5	50, F	ME	ACC	T4	yes	—/60	—	subtotal	positive	VII, VIII	none	11.6	AD
6	27, M	EAC	SCC	T4	yes	40/31	CDDP	total	positive	VII, VIII, XI	meningitis, encephalitis	0.7	DOD
7	51, F	PG	XPA	T4	yes	—/70	—	subtotal	positive	VII, VIII	none	1.9	DOD
8	59, M	ME	SCC	T3	no	—/60	CDDP/THP/5-FU	subtotal	negative	VII, VIII	none	7.3	NED
9	69, F	ME	SCC	T4	no	40/31	CDDP/THP/5-FU	subtotal (JB opening)	negative	VII, VIII	none	0.6	DOD (metastasis)
10	62, M	EAC	SCC	T4	no	28/40	CDDP	subtotal	negative	VII; VIII	none	2.9	NED
11	57, F	EAC	SCC	T4	no	30/40	—	subtotal	negative	VII, VIII	none	5.7	NED
12	64, M	EAC	SCC	T4	no	36/34	CDDP	subtotal	negative	VII, VIII	CSF leakage, transient	5.5	NED
13	67, F	EAC	SCC	T4	no	30/40	—	subtotal (JB opening)	positive	VII, VIII	none	5.2	NED
14	70, M	PG	ACC	T4	yes	50/—	—	subtotal (JB resection)	negative	V3, VII, VIII, IX, X	brainstem edema, dysphagia	2.8	NED
15	41, M	EAC	SCC	T4	no	—/60	—	subtotal (JB opening + OZ)	negative	V3, VII, VIII	subcutaneous abscess	1.9	NED
16	73, F	PG	MYC	T4	yes	70/—	—	subtotal (OZ)	negative	V3, VII, VIII	none	1.5	NED
17	35, M	PG	ACC	T4	yes	50/—	—	subtotal (OZ)	negative	V3, VII, VIII	none	0.3	NED

* ACC = adenoid cystic carcinoma; AD = alive with disease; adeno = adenocarcinoma; car = carcinoma; CDDP = cisplatin; CPM = cyclophosphamide; CSF = cerebrospinal fluid; DOC = died of other causes; DOD = died of disease; DXR = doxorubicin; Ewing = Ewing sarcoma; FU = follow-up; IFO = ifosfamide; JB = jugular bulb; ME = middle ear; MYC = myoepithelial carcinoma; NED = alive with no evidence of disease; OZ = orbitozygomatic osteotomy; PG = parotid gland; TB = temporal bone; THP = pirarubicin; VCR = vincristine; V3 = mandibular nerve; VP-16 = etoposide; XPA = carcinoma ex pleomorphic adenoma; XRT = radiotherapy; 5-FU = fluorouracil; — = not applicable.

† Classification based on University of Pittsburgh System (see Table 2).

TABLE 2

*University of Pittsburgh staging system for SCC of the temporal bone**

Status	Characteristics
T1	tumor limited to EAC w/o osseous erosion or evidence of soft-tissue extension
T2	tumor w/ limited EAC osseous erosion (not full thickness) or radiographic findings consistent w/ limited (<0.5 cm) soft-tissue involvement
T3	tumor eroding osseous EAC (full thickness) w/ limited (0.5 cm) soft-tissue involvement, or tumor involving ME &/or mastoid
T4	tumor eroding cochlea, petrous apex, medial wall of ME, carotid canal, jugular foramen, or dura mater, or w/ extensive (0.5 cm) soft-tissue involvement; patients presenting w/ facial paralysis
N	lymph node involvement (N1) as poor prognostic sign, placing patient in an advanced stage (that is, T1, N1 [Stage III], & T2, -3, or -4, N1 [Stage IV]); if lymph node not involved (N0), staging does not change
M	if metastasis present (M1), clinical stage is modified to Stage IV, which is considered a very poor prognostic sign; if metastasis not present (M0), staging determined by T & N status

* Clinical stage (TNM stage) is based on tumor (T) status and modified according to lymph node (N) and metastasis (M) status.

durally and resected along with the tumor mass. For tumors extending anteriorly to the temporomandibular joint that involved the medial and lateral pterygoid muscles, orbitozygomatic osteotomy was performed to provide a more anterior view (3 cases). Through this route, bone drilling was extended anteriorly along the carotid canal to the inferior orbital fissure by dividing the mandibular branch of the trigeminal nerve, and the pterygoid muscles were detached or cut close to the lateral pterygoid plate. This procedure allowed complete exposure of the petrous ICA to the extracranial space, while leaving the lateral tumor mass untouched. These procedures are schematically drawn in Fig. 1, and an illustrative intraoperative view after tumor resection is shown in Fig. 2 (Case 15).

Total TBR. In tumors extending to the petrous apex, total TBR was performed in 3 cases. Following exposure of the middle cranial fossa, the tumor around the carotid canal was first removed in a piecemeal fashion, and then standard subtotal TBR was performed. After resection of the main tumor mass, the remaining tumor and bone in the apex were removed.

Adjuvant Therapy

For patients who had been treated with radiotherapy, additional doses of radiation were administered postoperatively when possible. In the initial cases, preoperative radiotherapy of up to 40 Gy was administered in selected patients. Seven patients were treated with perioperative chemotherapy (Table 1).

Prognostic Factors and Statistical Analysis

To analyze factors that might influence local tumor control and survival, the pathologically verified surgical margin; preoperative imaging extensions to the petrous apex, infratemporal fossa, and jugular foramen; and dural extensions were evaluated by performing a Kaplan–Meier analysis followed by univariate analysis with the log-rank test (Dr SPSS II software, SPSS, Inc.). Statistical significance was set at a probability value < 0.05.

Results

Tumor Grading and Pathological Margin

Figure 3 depicts the tumor locations including extensions, according to a pathologically verified surgical margin. Although relatively small tumors were included in this study (such as in Cases 8 and 11), most of the lesions extended upward to elevate the dura or anteriorly into the infratemporal soft tissue. As a result, all tumors except 1 (Case 8, T3) were graded as T4 (Table 1).

Given that large tumors extended to the petrous apex in Cases 2, 4, and 6, total TBR was performed while preserving the petrous ICA, inevitably leading to a positive surgical margin (Fig. 3A). The patient in Case 1 harbored a large intracranial mass, which was resected in a piecemeal fashion. In Cases 5 and 7, the tumors were relatively small but involved the temporomandibular joint and pterygoid muscles; these anteriorly extending tumors were removed from the anterolateral direction in a piecemeal fashion.

After this initial experience, which resulted in poor patient survival, we introduced the orbitozygomatic osteotomy technique and achieved a negative surgical margin in Cases 15, 16, and 17. As shown in Fig. 3B, tumors in these cases were much larger than those in Cases 5 and 7. For tumors encroaching on the jugular foramen, the extradural posterior transjugular approach was combined with the standard temporal bone resection in 3 cases (Cases 9, 13, and 15). In another patient (Case 15), the tumor had invaded the lateral wall of the jugular bulb and sigmoid sinus, which was removed by the intradural route by directly opening the jugular bulb after a posterior transjugular approach. In 3 of these 4 cases, a negative surgical margin was successfully achieved; in the patient in Case 13, a small hard tumor mass attached to the fibrous band of the jugular vein was also removed.

Local Tumor Control and DSS

All patients, except 1 (Case 10), were followed up until death or the end of the study. During the follow-up period, local tumor recurrence was observed in 5 patients within the first 1.2 years (Fig. 4A); all of these patients died within 2 years of treatment. No local tumor recurrence was seen 2 years after surgery. The overall RFS rate was 67.5% at 5 years posttreatment.

One patient (Case 8) died following distant metastasis 6 months after surgery, despite having a negative surgical margin and good local tumor control. Another patient (Case 3) died of unrelated causes (pneumonia) without evi-

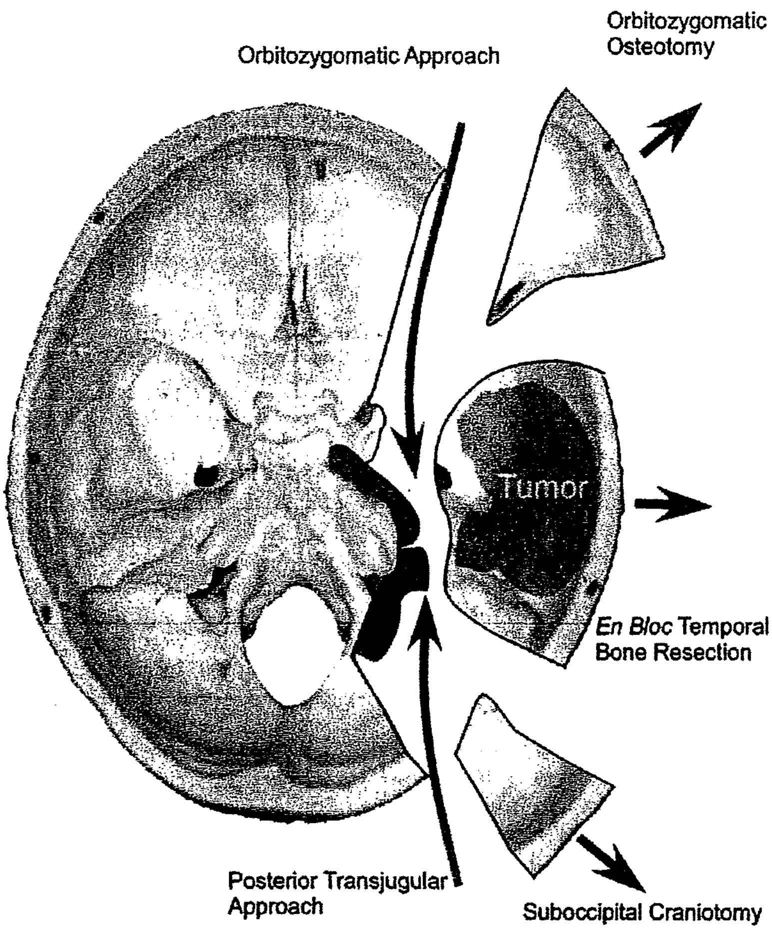

FIG. 1. Drawing illustrating the extent of subtotal TBR for tumors with infratemporal fossa and jugular foramen extension. En bloc resection of the lateral temporal bone can be achieved with a combined orbitozygomatic osteotomy and posterior transjugular approach, which provide anterior and posterior routes to the carotid canal and jugular foramen, respectively. *Red* indicates the carotid artery, and *blue* indicates the sigmoid sinus and jugular bulb.

dence of recurrence 5.4 years after surgery. Thus, the 5-year DSS rate was 60.1% (Fig. 4B). No patient who survived > 2 years showed evidence of disease, with the exception of the patient in Case 5 who had relatively stable multiple lung metastases of adenoid cystic carcinoma.

Prognostic Factors

The most important local prognostic factors for temporal bone malignancy are the size and extension of the tumor, which have been graded by several authors.[1,10,13,32,34] According to the University of Pittsburgh tumor grading system, all of the lesions in the present study were graded T4 (most advanced), except 1 (Case 8); therefore, we did not include tumor grading as a potential prognostic factor.

Instead, we evaluated the effects of a pathologically verified surgical margin; tumor extension to the petrous apex, infratemporal fossa, and jugular foramen; and dural involvement on RFS and DSS (Table 3). Both types of survival were significantly affected by surgical margin and petrous apex extension. None of the patients with a negative surgical margin (10 patients) had a local recurrence, and all of them had a 5-year RFS rate of 100%; those with a positive surgical margin (7 patients) had a local recurrence within 1.2 years posttreatment and a 5-year RFS rate of 29% (p = 0.003; Fig. 4A). Similarly, the 5-year DSS rates in patients with negative and positive surgical margins were 89 and 29%, respectively (p = 0.03; Fig. 4B).

All patients with petrous apex extensions (3 patients) who had undergone total TBR had a local recurrence within 1.2 years postsurgery and died within 2 years of surgery; those without petrous apex extensions had RFS and DSS rates of 84 and 75%, respectively, 5 years after treatment (p = 0.004 and p = 0.006, respectively). The 3 other factors evaluated had no significant effect on RFS and DSS, although jugular foramen extensions were marginally significant in DSS (Table 3).

Surgical Complications

The surgical complications are shown in Table 1. Cranial nerves VII and VIII were sacrificed during surgery in all but 1 patient (Case 1), which resulted in facial palsy and deafness. The mandibular branch of the CN V (V3) was also sacrificed in 5 patients. In the patient in Case 14, lower CNs were resected because of apparent tumor invasion with resultant postoperative dysphagia. No other new neurological deficits were noted postoperatively. Severe infections developed in 2 of the initial 8 cases. In the patient in Case 1, the infection may have arisen from the dead space that remained after the tumor invading the brain had been resected. In the patient in Case 6, a large tumor eroding the skin had been infected preoperatively due to tumor necrosis, which resulted in severe meningitis and encephalitis. Both patients were successfully treated with antibiotic therapy. In the final 9 cases, the most severe complication was brainstem edema, which was caused by resection of the jugular bulb but subsided within 2 weeks. This patient suffered no permanent brainstem symptoms. The overall and major surgical complication rates, unrelated to a planned sacrifice of CNs, were 29 and 18%, respectively. None of the patients died of surgical complications.

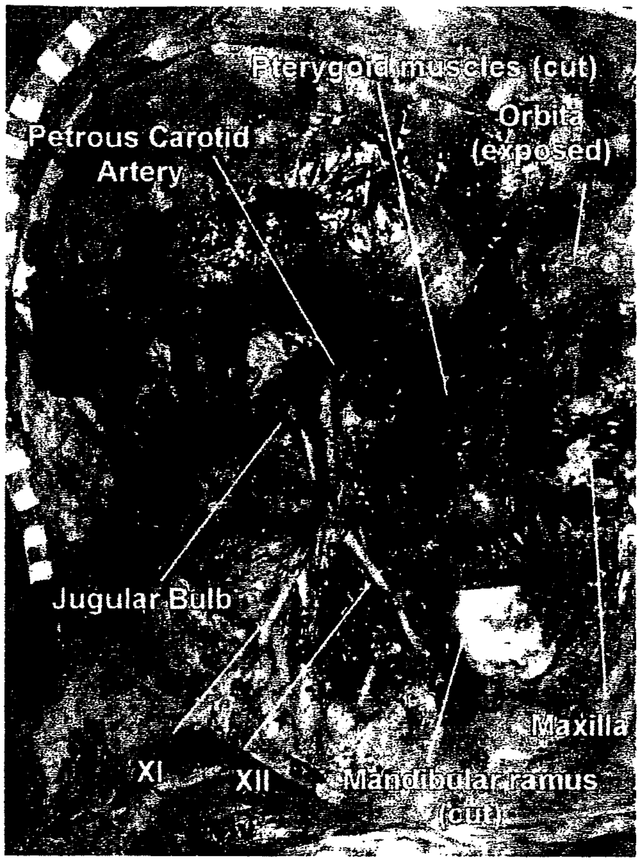

FIG. 2. Case 15. Photograph obtained after en bloc subtotal TBR via the orbitozygomatic and posterior transjugular approaches, showing complete removal with a tumor-free margin. The maxilla, orbit, jugular bulb, and ICA were all exposed after removal of the lesion. XI = accessory nerve; XII = hypoglossal nerve.

Discussion

Primary malignancies involving the lateral skull base originate from sites such as the EAC, middle ear, and petrous bone or extend from the parotid gland. The rarity, histological heterogeneity, and anatomical complexity of these lesions make direct comparisons difficult, although they have been made easier by the proposal of several preoperative staging systems.[1,10,21,28,32–34] Recent studies in which these classifications have been used are summarized in Table 4, as are the treatment modalities and outcomes. The University of Pittsburgh grading system proposed by Arriaga et al.[1] and Hirsch[13] is most frequently applied to the various malignancies and was used in the present study (Table 2).

As expected, the prognosis of small or early-grade tumors was excellent, with long-term survival rates of usually > 70%, regardless of the grading system (Table 4). However, the outcome in patients with advanced tumors was poor, with survival rates ranging from 0–50%. Focusing solely on University of Pittsburgh grading studies, the 5-year survival rates for T4 or Stage 4 tumors were 16–41%.[24,26,29,35,38] Therefore, the overall 5-year survival rate of 60% in patients with advanced tumors in the present study compares favorably.

Most treatments for these malignancies are a type of TBR. The extent of resection must be tailored to the location and extension of the tumor, which is basically classified into 4 types (for a review, see Willging and Pensak[37]). Canal or sleeve resection via cortical mastoidectomy is used for lesions confined to the cartilaginous portion of the EAC and can be extended to include the total osseous canal lateral to the stapes (lateral or partial TBR). Subtotal TBR is indicated for tumors extending into the mastoid or middle ear (T3 tumors) or much larger and more extensive lesions (T4). The principle of this en bloc procedure was first described by Parsons and Lewis.[27] For tumors extending to the petrous apex, total TBR is often indicated, and resection of the apex is inevitably piecemeal.

En bloc resection has been used for extensive tumors in the majority of recently reported studies (Table 4), with subtotal TBR documented in < 12 cases in these studies, except in those by Goodwin and Jesse[10] and Moffat et al.[24] Moreover, because of difficulties with en bloc resection, some lesion parts have been resected in a piecemeal fashion, as described by Moody et al.[25] and McGrew et al.[22] Accordingly, most outcomes following en bloc resection of Grade T4 tumors remain poor and are comparable to outcomes in other studies of piecemeal gross-total resection.[4,16,39] Despite these difficulties, en bloc resection with a tumor-free margin is reportedly a major prognostic indicator of excellent long-term survival ranging from 75–100% at 5 years posttreatment.[2,10,25,26,29,38] Compare this rate with that in patients with a positive surgical margin, who usually die within 2 years posttreatment. Thus, the most critical issue for improving long-term outcome in patients with Grade T4 tumors appears to be enhancing en bloc resectability.

Our initial experience with extensive tumors (Grade T4) was similar in that en bloc resection with a tumor-free margin was technically difficult and led to poor patient survival. To overcome this trend, we introduced 2 methods. The first method was orbitozygomatic osteotomy, which allowed wider access to intracranial skull base lesions while minimizing brain retraction.[7,12] This technique, which was later modified and renamed the "orbitozygomatic infratemporal fossa approach,"[12,18] also provided a wider view of the infratemporal fossa,[14] particularly from the anterior direction. Performing an anterior or infratemporal tumor resection reportedly has been associated with a poor

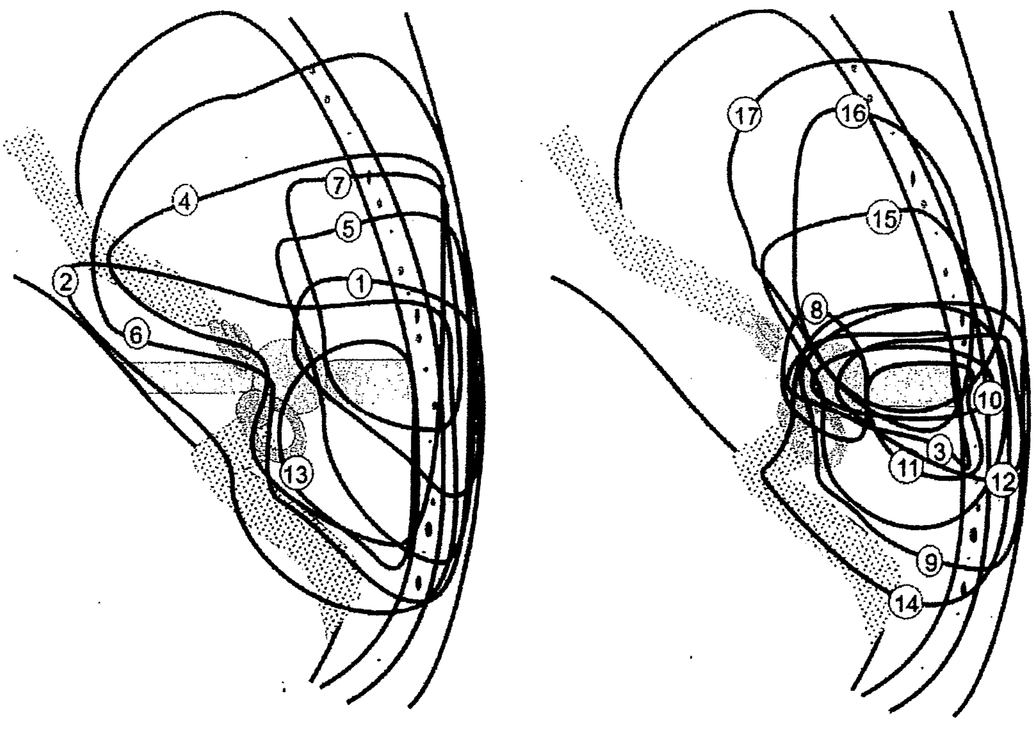

FIG. 3. Schematics revealing tumor locations and extensions in the temporal bone according to case number. A: Tumors in which a positive surgical margin was verified pathologically. B: Tumors with a negative surgical margin.

prognosis.[21] By using this technique in the present study, we achieved en bloc resection of tumors extending into the infratemporal fossa with a negative surgical margin, and these lesions were larger than those in previous cases.

The second method was the direct posterior approach to the jugular foramen without entering the mastoid process. A popular technique in the field of otolaryngology is the infralabyrinthine approach through a partial mastoidectomy,[17] which leads to tumor exposure or transection of large Grade T4 tumors extending to the jugular foramen. In the neurosurgical literature, however, the posterior approach as an extension of a suboccipital craniotomy without mastoidectomy, which provides an advantage in lateral base malignancies, has been described by Hakuba et al.,[11] Sasaki and Takakura,[31] George et al.,[8] and Kawahara et al.[15] We therefore used this approach in 4 cases in the latter half of the series and achieved a negative surgical margin in 3 of these cases. The introduction of these techniques markedly improved the probability of successful en bloc resection and survival (Table 1 and Fig. 3B). Recurrence-free survival and DSS rates 5 years after treatment in patients with a negative surgical margin were excellent (100 and 89%, respectively, vs 29% with a positive margin). Because of the high rate of negative surgical margins, the overall DSS rate 5 years after treatment improved to 60% among our series, which exceeded the rate in many previous studies (Table 4).

Another factor associated with poor patient survival is dural invasion. In the present study, preoperative MR imaging suggested dural invasion in 8 cases. Although overt brain invasion was apparent in 1 of these cases, the tumors in the other 7 did not invade intradurally and were completely resected with a wide safety margin. Thus, dural involvement on preoperative imaging studies did not affect long-term tumor control and survival.

Lesion extension to the petrous apex is usually resected piecemeal in total TBR, and the performance of this technique is usually associated with a worse 5-year survival rate than subtotal TBR,[25] which was estimated to be 0% in a systematic review by Prasad and Janecka.[30] It is also related to the issue of ICA sacrifice, and in this regard, Brisman et al.[5] have recommended ICA sacrifice and revascularization for extensive tumors. In their study, however, only 1 patient with adenoid cystic carcinoma out of 7 who had undergone carotid sacrifice and revascularization survived > 2 years without tumor recurrence, for a major complication rate of 71%. This outcome is similar to that in the present study, in which all 3 patients with petrous apex extension who had undergone total TBR with ICA preservation died within 2 years of surgery. Based on these results, we believe that curative resection for these tumors is rarely possible and that ICA sacrifice does not improve the survival rate but rather increases the likelihood of complications.

Given the relatively high risks of en bloc surgery, piecemeal resection combined with radiotherapy has been recommended by Kinney and Wood[16] and Birzgalis et al.,[4] for a survival rate of 37–45% (Table 4). Authors of these early

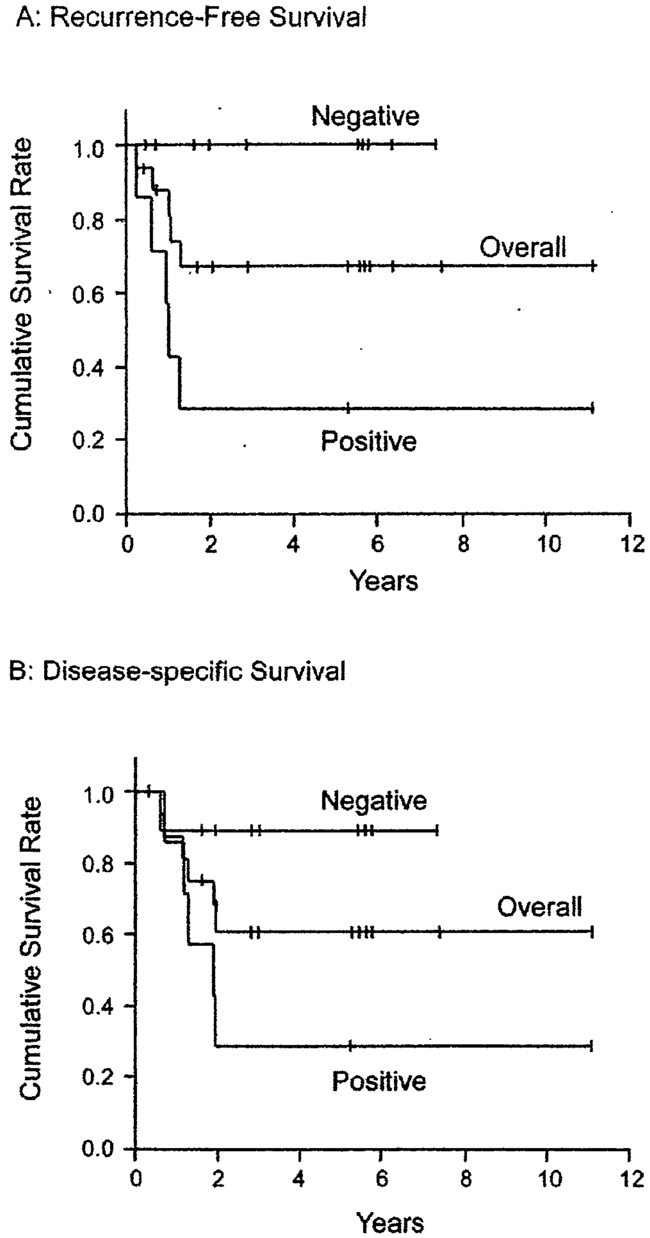

FIG. 4. Kaplan–Meier curves for RFS (A) and DSS (B). Negative = negative surgical margin; Positive = positive surgical margin.

TABLE 3
Factors predictive of RFS and DSS in 17 patients with skull base malignancy

Parameter	No. of Patients	p Value RFS	p Value DSS
surgical margin		0.003*	0.031*
positive	7		
negative	10		
tumor extension to			
petrous apex	3	0.004*	0.006*
infratemporal fossa	6	0.102	0.199
jugular foramen	6	0.179	0.048*
dura mater	8	0.099	0.278

* Statistically significant on univariate analysis with log-rank test.

studies used different classification systems, and therefore, the results cannot be compared with those in other reports. Although radiotherapy is usually combined with surgery in the treatment of such tumors, a recent study in which the University of Pittsburgh classification scheme was used revealed the limitations of conventional radiotherapy for advanced tumors, with a disappointing 5-year survival rate of 20% for Grade T4 tumors.[39]

In contrast, new technologies, such as 3D conformal radiotherapy, IMRT, and charged-particle therapy, can now be applied in the treatment of various head and neck malignancies.[3] In the context of charged-particle therapy, the 5-year overall local control and survival rates have been 60 and 33%, respectively, for carbon-ion therapy[23] and 74 and 44%, respectively, for proton beam therapy.[36] Even better results have been reported following IMRT for nasopharyngeal carcinoma, in which the 3- to 4-year local control and overall survival rates have been estimated as 82–98% and 77–88%, respectively, although the follow-up period remains short.[6,19] Based on these preliminary data, we predict that more patients will be treated using new radiotherapy alone or in combination with surgery.

However, these data should be analyzed with caution. Squamous cell carcinoma, which is the most common histological subtype, is the least responsive to charged-particle therapy (with a 5-year local control rate of 34%) and patient survival is poor,[23] indicating that the presence of some viable tumor cells can contribute to distant metastasis.[23,36] In addition, the good IMRT results for nasopharyngeal carcinoma might not be applicable to temporal bone malignancies, as the dosage must be limited to avoid possible side effects to adjacent brain. Therefore, we still recommend radical en bloc TBR aiming for a negative surgical margin, which has the potential to produce a 5-year survival rate of > 75%.[2,10,25,26,29,38]

Conclusions

Despite progress in skull base techniques in head and neck surgery and neurosurgery, the long-term prognosis of large lateral skull base malignancies remains poor. This poor prognosis is mostly related to the probability of en bloc tumor resection. While working as a multidisciplinary team, we have combined surgical techniques commonly used in the neurosurgical field (namely orbitozygomatic infratemporal fossa and posterior transjugular approaches) and improved the resectability of lesions and long-term survival of our patients. More active participation of neurosurgeons could further improve the probability of successful en bloc resection of these tumors. Lesions involving the brain and those extending to the petrous apex with ICA involvement still carry the worst prognosis. We believe that radical TBR is not curative in such cases and therefore should rarely be indicated. In such cases, new radiotherapies (such as IMRT or charged-particle therapy) could be used alone or in combination with less invasive palliative surgery.

TABLE 4

Literature summary of studies on TBR for malignant tumors

Authors & Year	No. of Cases	Tumor Classification (no. of cases)	Type of Surgery (no. of cases)	Resection Policy	Survival Rate	Prognostic Factor
Goodwin & Jesse, 1980	136	Group 1: cartilaginous EAC (76), Group 2: osseous EAC (22), Group 3: medial to ME (38)	subtotal TBR (25) for Group 3, other treatment (111) for Groups 1, 2, and 3	en bloc	all at FU of 5 yrs, Group 1: 57%, Group 2: 45%, Group 3: 29%	surgical margin
Kinney & Wood, 1987	30	Group 1: limited to EAC (12), Group 2: limited extension beyond EAC (7), Group 3: extension outside EAC (11)	piecemeal resection (29), radical TBR (1)	piecemeal	all at average FU of 2.5 yrs, Group 1: 91%, Group 2: 72%, Group 3: 45%	NA
Go et al., 1991	16	NA	partial TBR (4), total TBR (12)	en bloc	for malignant tumors, FU of 5 yrs, 56%	NA
Spector, 1991	34	EAC (7), superficial invasion (3), deep invasion (10), beyond TB (14)	canal resection (7), partial TBR (3), subtotal TBR (10), ITF (14)	en bloc	all at average FU of 36.6 mos, EAC + superficial invasion: 100%, deep invasion: 70%, beyond TB: 65%	
Birzgalis et al., 1992	66	early presentation (10), late presentation (39), not classified (17)	radical XRT (53), palliative XRT (7), not treated (6)	piecemeal	all at FU of 5 yrs, early presentation: 80%, late presentation: 26%, all treated: 32%, radical XRT: 37%, palliative XRT: 0%	tumor stage
Austin et al., 1994	22	UP grading: T1 (8), T2 (4), T3 (6), T4 (4)	canal resection (7), partial TBR (7), subtotal TBR (4), total TBR (2), other treatment (2)	en bloc	all at FU of 3 yrs, T1–T2: 75%, T3: 50%, T4: 50%, en bloc resection + XRT (6 patients): 100%	en bloc resection, adjuvant XRT
Pensak et al., 1996	46	Grade I: single tumor ≤1 cm (3), Grade II: single tumor >1 cm (14), Grade III: transannular extension (6), Grade IV: mastoid or petrous invasion (5), Grade V: extratemporal extension (10), Grade VI: neck adenopathy, distant, ITF (8)	canal resection (1), lat TBR (16), modified lat TBR (13), total TBR (9), other treatment (7)	en bloc	rate w/ no evidence of tumor, all at FU of 5 yrs, Grade I–II: 82%, Grade III: 67%, Grade IV: 40%, Grade V: 75%, Grade VI: 0%	NA†
Testa et al., 1997	79	UP grading: T1 (8), T2 (26), T3 (27), T4 (16), unknown (2)	canal resection (37), partial TBR (15), subtotal TBR (6), total TBR (1), other treatment (20)	NA	all at FU of 5 yrs, Stage 1–2: 77–100%, Stage 3: 45%, Stage 4: 16%, XRT only: 29%, subtotal + total TBR: 43%	tumor type, clinical stage, surgery, bone erosion
Manolidis et al., 1998	30	Group 1: epithelial tumors (30); Stage 1: confined to EAC (15); Stage 2: TMJ, parotid, ITF (5); Stage 3: ME, mastoid, facial nerve (4); Stage 4: dura, JB, SS, ICA, petrous apex (6)	lat TBR (22), total TBR (6), other (2)	NA	all at average FU of 54 mos, Stage 1: 80%, Stage 2: 80%, Stage 3: 25%, Stage 4: 0%	pain, facial paralysis, ITF extension
Pfreundner et al., 1999	27	UP grading: T1 (7), T2 (2), T3 (6), T4 (12)	local resection (10), partial TBR (14), subtotal TBR (1), other treatment (2)	NA	all at FU of 5 yrs, T1–2: 86%, T3: 50%, T4: 41%, negative margin: 100%, positive margin: 66%	dural/cerebral invasion, surgical margin
Zhang et al., 1999	33	UP grading: T1 (2), T2 (1), T3 (19), T4 (11)	gross resection (22), XRT only (11)	piecemeal	FU of 3 yrs, Stage 1–2: 100%; all at FU of 5 yrs, Stage 3: 69%, Stage 4: 20%, total: 29%, XRT alone: 28.7%	NA
Moody et al., 2000	32	UP grading: T1 (7), T2 (5), T3 (6), T4 (14)	modified lat TBR (3), lat TBR (18), subtotal TBR (6), total TBR (5)	medial margin: piecemeal	all at FU of 2 yrs, T1: 100%, T2: 80%, T3: 50%, T4: 7%, subtotal TBR: 33%, total TBR: 0%, negative margin: 75%, positive margin: 32%	surgical margin, dural invasion
McGrew et al., 2002	95	NA	lat TBR (NA), subtotal TBR (NA), total TBR (NA)	en bloc usually	at average FU of 50 mos, entire group: 63–74% (subtotal TBR excluded)	NA
Yeung et al., 2002	59	UP grading: T1–T4, no. NA	canal resection (20), lat TBR (30), subtotal TBR (9)	en bloc	all at FU of 5 yrs, Stage 1: 90%, Stage 2: 45%, Stage 3: 40%, Stage 4: 19%, negative margin: 80%, positive margin: 30%, subtotal TBR: 22%	surgical margin, histological features
Moffat et al., 2005	39	UP grading: T1 (0), T2 (2), T3 (6), T4 (31)	lat TBR (4), extended TBR (33), other treatment (2)	en bloc	at average FU of 7.6 yrs, T2: 100%, T3: 50%, T4: 38%; at FU of 2 yrs, overall: 39%	lymph node–positive, poor differentiation, brain involvement, salvage surgery
Nakagawa et al., 2006	25	UP grading: T1 (1), T2 (3), T3 (5), T4 (16)	lat TBR (7), subtotal TBR (5), conservative treatment (13)	en bloc	at FU of 3 yrs, T1–2: 100%; all at FU of 5 yrs, T3: 80%, T4: 35%, T4 w/ surgery: 75%, T4 w/o surgery: 16%	surgery, surgical margin, N status

* ITF = infratemporal fossa; NA = not available; SS = sigmoid sinus; TMJ = temporomandibular joint; UP = University of Pittsburgh.
† Authors listed contraindications instead, which were invasion of the cavernous sinus, ICA, ITF, and paraspinal musculature.