Surgical Simulation of Extradural Anterior Clinoidectomy through the Trans-superior Orbital Fissure Approach Using a Dissectable Three-dimensional Skull Base Model with Artificial Cavernous Sinus

Kentaro Mori, M.D., Ph.D.,¹ Takuji Yamamoto, M.D., Ph.D.,¹
Yasuaki Nakao, M.D., Ph.D.,¹ and Takanori Esaki, M.D., Ph.D.¹

ABSTRACT

Extradural anterior clinoidectomy via the trans-superior orbital fissure (SOF) approach can provide extensive exposure of the anterior clinoid process and safe drilling under direct view. This technique requires peeling of the dura propria of the temporal lobe from the lateral wall of the SOF. Therefore, cadaveric dissection is mandatory to acquire surgical technique. However, chances for cadaveric dissection are limited. We propose modification of our three-dimensional (3-D) skull base model made from surgically dissectable artificial bone with artificial cavernous sinus including multiple membranous layers and neurovascular structures to simulate extradural anterior clinoidectomy via the trans-SOF approach. The 3-D skull base model precisely reproduced the dura propria of the temporal lobe, periosteal bridge, and inner reticular layer in the cavernous sinus and SOF using silicone and varnish. The cranial nerves and blood vessels were made from rubber fibers and vinyl tube. Simulation of extradural anterior clinoidectomy via the trans-SOF approach could be performed on the model using a high-speed drill under the operating microscope. The steps of reconstruction of the skull base model and dissection promote clear understanding of the 3-D anatomy and techniques of extradural anterior clinoidectomy via the trans-SOF approach.

KEYWORDS: Anterior clinoid process, superior orbital fissure, cavernous sinus, anterior clinoidectomy, training model

Anterior clinoidectomy through the intradural approach or extradural approach is one of the essential skull base techniques to treat cerebral aneurysms of the internal carotid artery (ICA) and basilar artery and skull base tumors. Extradural anterior clinoidectomy includes

two main techniques: selective extradural anterior clinoidectomy without peeling the lateral wall of the cavernous sinus (CS), which requires opening of the optic canal and en bloc removal of the anterior clinoid process (ACP), and extradural anterior clinoidectomy

¹Department of Neurosurgery, Juntendo University, Shizuoka Hospital, Shizuoka, Japan.

Address for correspondence and reprint requests: Kentaro Mori, M.D., Ph.D., Professor, Department of Neurosurgery, Juntendo University, Shizuoka Hospital, 1129 Nagaoka, Izunokuni, Shizuoka 410-2295, Japan (e-mail: kmori@med-juntendo.jp).

Skull Base 2010;20:229–236. Copyright © 2010 by Thieme

Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662.

Received: October 3, 2009. Accepted: November 11, 2009. Published online: January 29, 2010.

DOI: <http://dx.doi.org/10.1055/s-0030-1247632>.
ISSN 1531-5010.

through the trans-CS approach, which requires peeling of the lateral wall of the CS to expose the entire ACP for drilling. Recently, the latter method has been refined by minimizing the area of peeling in the lateral wall of the superior orbital fissure (SOF), including the anterior part of the CS that requires extradural exposure of the ACP. This improved technique, extradural anterior clinoidectomy through the trans-SOF approach, requires experience with the surgical anatomy of the SOF and CS and the peeling technique of the lateral wall of the CS. In particular, the surgeon must have good knowledge of the osseous structure of SOF, the neurovascular structures passing through the SOF, and the membranous structures including the periorbita, periorbital bridge, and walls of the CS. The two-dimensional photos and drawings illustrating cadaveric dissection or extradural anterior clinoidectomy may not be adequate for the neurosurgical resident to understand this technique. Therefore, hands-on cadaveric dissection is essential to understand the anatomy of the SOF and experience the surgical technique.

We have developed a new educational tool for the training of neurosurgeons before cadaveric dissection and neurosurgical practice. The selective laser sintering method based on recent advanced computer technology now allows convenient three-dimensional (3-D) reproduction of objects.¹ A 3-D model of the human skull has been manufactured by the rapid prototyping method based on the 3-D computed tomography data of the human skull using the selective laser sintering method. The 3-D skull model precisely reproduces both the surface details and the inner bony structures.² This 3-D skull model is made from artificial bone material containing glass beads and can be dissected with normal surgical drills.² We previously reported the usefulness of modified dissectable 3-D temporal or skull base models with artificial dura mater, venous sinuses, cranial nerves, and ICA for training in skull base surgery.³⁻⁶

Here we focus on the surgical simulation of extradural anterior clinoidectomy via the SOF approach with the minipeeling technique using the 3-D skull base model with artificial dura mater and CS-related structures. The surgical simulation was performed with real surgical tools under the operating microscope and is compared with a case of paraclinoid large aneurysm treated by this technique.

MATERIALS AND METHODS

Construction of Modified 3-D Skull Base Model with Artificial Dura Mater and CS

The dissectable 3-D half skull base model (OMeR-KEZLEX-SB-LH; Ono & Co., Ltd., Tokyo, Japan) was modified for surgical simulation of extradural anterior clinoidectomy via the SOF with the minipeeling

technique. This 3-D skull base model reproduced all the structures needed for surgical simulation, including the ACP, optic canal, optic strut, SOF, foramen rotundum (FR), foramen ovale (FO), and so on (Fig. 1A). The methods to modify the prototype skull model with artificial dura mater and CS were previously reported.³⁻⁶ Briefly, varnish was painted on the inner surface of the skull for the easy dissection of the artificial dura mater from the skull. The periosteal layer of the dura mater was formed of yellow silicone (hydrophilic vinyl polysiloxane impression material, Exafine Hard Type; GC Corporation, Tokyo, Japan) painted onto the inner surface of orbit to reproduce the periorbita, and on the parasellar area of sphenoid bone to reproduce the medial wall of the CS. The lateral margin of the medial wall of the CS corresponds to the lateral edges of the SOF, FR, and FO. The periosteal bridge was formed by fusing the two yellow silicone layers of the periorbita and medial wall of the periosteal layer at the lateral part of the SOF (Fig. 1A). The venous plexuses of the CS were modeled by brushing blue silicone (Exafine Regular Type; GC Corporation) onto the yellow silicone of the medial wall (Fig. 1A). The C1 to C6 portions of the ICA and middle meningeal artery were modeled with red vinyl tubes. The oculomotor nerve, trochlear nerve, and the ophthalmic division of the trigeminal nerve were modeled with yellow rubber fibers, and then positioned in the SOF. The maxillary and mandibular divisions of the trigeminal nerve were positioned in the FR and FO, respectively (Fig. 1B). In the present model, the dura mater except for the CS-related areas was reconstructed with a single layer of meningeal dura modeled with brown silicone (Exafine Injection Type; GC Corporation), which was thin, dissectable, and retractable. The inner reticular layer of the lateral wall in the CS was reconstructed with varnish to form a semitransparent membrane on the cranial nerves and venous plexus in the CS (Fig. 1B). Finally, the dura propria (meningeal layer) of the lateral wall of the CS was modeled with brown silicone on the inner reticular layer (Fig. 1C).

RESULTS

Surgical Simulation of Extradural Anterior Clinoidectomy by the Trans-SOF Approach

Extradural anterior clinoidectomy by trans-SOF approach was simulated according to the method previously reported.⁷ The modified 3-D skull model was fixed with a Mayfield three-point fixation device. After standard frontotemporal craniotomy was performed, the temporal squama was rongeuired until the anterior part of the middle cranial fossa was exposed (Fig. 2A). Under the operating microscope, the sphenoid ridge was drilled away and flattened until the periosteal bridge (fold) in the lateral part of the SOF was exposed (Fig. 2B). The

Figure 1 Process to modify the 3-D half skull base model. (A) Oblique lateral view of the half skull base model. Periosteal layers of the dura mater in the medial wall of the cavernous sinus, periorbita, and periosteal bridge in the superior orbital fissure are modeled with yellow silicone. Dural sinuses such as the cavernous sinus, superior petrosal sinus, and inferior petrosal sinus are modeled with blue silicone. (B) Meningeal layer of the dura mater is modeled with brown silicone. The internal carotid artery is modeled with red vinyl tube. Abducens nerve, oculomotor nerve, trochlear nerve, and ophthalmic division of the trigeminal nerve are modeled with yellow rubber fibers positioned in the superior orbital fissure. The maxillary division and mandibular division of the trigeminal nerve are positioned in the foramen rotundum and foramen ovale, respectively. The semitransparent inner reticular layer is represented with varnish painted on the neurovascular structures in the cavernous sinus. (C) Dura propria of the lateral wall of the cavernous sinus is modeled with brown silicone. ACP, anterior clinoid process; CS, cavernous sinus; DP, dura propria of the lateral wall of the cavernous sinus; FO, foramen ovale; FR, foramen

frontal dura was subperiosteally dissected from the orbital roof, and the temporal dura was dissected from the greater wing of the sphenoid bone until the FR was exposed. The periosteal bridge was incised using microscissors from its lateral end to 4 mm along the sphenoid ridge (Fig. 2C). The dura propria of the temporal dura was peeled off from the lateral part of the SOF using a microdissector (Fig. 2D). The peeling was directed from the SOF to the FR. The oculomotor nerve, trochlear nerve, and the ophthalmic division branch of the trigeminal nerve were visible through the semitransparent membrane (inner reticular layer of the lateral wall of the CS; Fig. 3A). This anteriorly limited peeling procedure of the dura propria of the temporal dura from the lateral wall of the SOF to the anterior part of CS is called “mini-peeling.” This mini-peeling facilitates the complete exposure of the lateral surface of the ACP up to its tip. However, the mini-peeling should be minimized until the ACP is totally exposed to prevent mechanical injury to the cranial nerves in the SOF and CS. After completion of the mini-peeling in the SOF, the entire ACP was dissected out (Fig. 3B). Drilling of the ACP was performed using a diamond drill under continuous irrigation with cold normal saline to prevent heat injury to the neurovascular structures. The drilling was started from the lateral aspect of the ACP and then continued toward its medial part. Extreme care should be taken during drilling of the inferolateral part of the ACP where the oculomotor nerve passes. The thinned shells of the cortical bone of the ACP were left on the periosteal layer in the clinoid space. The fragments were removed using a microdissector (eggshell technique) to expose the clinoid space. The clinoid segment of the ICA could be observed in the clinoid space (Fig. 3C). The optic canal was opened using a diamond drill, similar to drilling of the ACP. Finally, only the optic strut remained between the opened clinoid space and the optic canal (Fig. 3C). The optic strut was dissected from the optic sheath and removed with a micropunch (Fig. 3D). This procedure did not require opening of the orbital roof.

Illustrative Case

A 56-year-old woman consulted our institution because of left medial visual field deficit. Cerebral angiography showed a large paraclinoid aneurysm of the left ICA

Figure 1 (Continued) rotundum; GG, gasserian ganglion; IC, internal carotid artery; III, oculomotor nerve; IPS, inferior petrosal sinus; IV, trochlear nerve; OC, optic canal; ON, optic nerve; PB, periosteal bridge; PCP, posterior clinoid process; SOF, superior orbital fissure; SPS, superior petrosal sinus; V1, ophthalmic division of the trigeminal nerve; V2, maxillary division of the trigeminal nerve; V3, mandibular division of the trigeminal nerve; VI, abducens nerve.

Figure 2 Procedure of extradural anterior clinoidectomy via the trans-SOF approach using the modified 3-D half skull base model. (A) After frontotemporal craniotomy, the frontal and temporal dura mater is dissected from the lesser wing and greater wing of the sphenoid bone. (B) After drilling the sphenoid ridge, the periosteal bridge is revealed between the orbit and the temporal fossa dura. (C) The periosteal bridge is incised along the SOF. (D) The dura propria of the temporal lobe is peeled from the SOF. SR, sphenoid ridge; TD, temporal fossa dura; FD, frontal fossa dura; GW, greater wing of the sphenoid bone; LW, lesser wing of the sphenoid bone; PB, periosteal bridge; FR, foramen rotundum; SOF, superior orbital fissure; SPB, stamp of the periosteal bridge.

(Fig. 4A). The aneurysm was attached to the anterior clinoid process and the medial part of the process was eroded (Fig. 4B). The patient was positioned in the supine position with the head turned away from the operative side at 30 degrees. Semicoronal skin incision and interfascial dissection were performed to separate the skin flap and temporal muscle flap and to expose the base of the middle fossa. After standard frontotemporal craniotomy, the temporal squama was rongeured. The sphenoid ridge was flattened until the periosteal bridge in the SOF was exposed (Fig. 5A). The dura mater was dissected in both lesser and greater wings of the sphenoid bone until the apertures of the optic canal and the FR were exposed. The periosteal bridge was incised with microscissors 4 mm along the SOF. Bleeding from the meningo-orbital artery was coagulated and cut. Using the dissector, minipeeling was performed to dissect the dura propria of the temporal lobe from the inner reticular layer in the SOF (Fig. 5B). The blunt dissection was started from the SOF to the RO until the orbital fat was revealed at the inferior end of the SOF. The oculomotor nerve and ophthalmic division of the trigeminal nerve

were observed from the inner reticular layer (Fig. 5B). The whole ACP was carefully dissected out and drilled from the lateral part. The centrally cored tip of the ACP was first removed, and the drilling was continued to the base of the clinoid. The clinoid segment of the ICA was identified in the opened clinoid space (Fig. 5C). The optic canal was opened. The diamond drill was continuously irrigated with cold normal saline during drilling of the ACP and optic canal. The optic strut was finally removed (Fig. 5C). The dura was opened along the sylvian fissure. The distal dural ring was cut. The falci-form ligament was also partially sectioned (Fig. 6A). The saccular aneurysm in the paraclinoid region was exposed and dissected from the compressed intradural optic nerve. Neck clipping was then performed (Fig. 6B).

DISCUSSION

Extradural anterior clinoidectomy was originally described as part of an extensive transcavernous approach in 1985 by Dolenc and other extradural skull base pioneers.⁸⁻¹¹ This technique was then developed as a

Figure 3 Procedure of extradural anterior clinoidectomy via the trans-SOF approach using the modified 3-D half skull base model (continued). (A) After completion of minipeeling, the entire anterior clinoid process is exposed. (B) Drilling of the anterior clinoid process under direct view. (C) Opened clinoid space and clinoid segment of the internal carotid artery are exposed. The optic canal is opened. The optic strut remains between the opened clinoid space and optic canal. (D) After removal of the optic strut. ACP, anterior clinoid process; C3, clinoid segment of the internal carotid artery; DP, dura propria of the lateral wall of the cavernous sinus; FD, frontal fossa dura; III, oculomotor nerve; IV, trochlear nerve; ON, optic nerve; OS, optic strut; TD, temporal fossa dura; V1, ophthalmic division of the trigeminal nerve; V2, maxillary division of the trigeminal nerve. Triangle indicates the clinoid space.

Figure 4 (A) Left carotid angiogram showing a paraclinoid aneurysm of the internal carotid artery. (B) The aneurysm is attached to the anterior clinoid process (arrow) and the medial part is eroded.

Figure 5 Intraoperative photographs of surgery for the paraclinoid aneurysm of the left internal carotid artery. (A) The temporal fossa dura and frontal fossa dura are dissected from the greater and lesser wings of the sphenoid bone. The periosteal bridge is exposed. (B) After minipeeling of the dura propria from the SOF. The ophthalmic division of the trigeminal nerve and oculomotor nerve are visible through the inner reticular layer. The whole ACP is exposed. (C) After drilling of the ACP, the clinoid segment of the carotid artery are exposed in the opened clinoid space. ACP, anterior clinoid process; C3, clinoid segment of the internal carotid artery; CS, clinoid space; DP, dura propria of the lateral wall of the cavernous sinus; FD, frontal fossa dura; GW, greater wing of the sphenoid bone; LW, lesser wing of the sphenoid bone; FR, foramen rotundum; III, oculomotor nerve; ON, optic nerve; PB, periosteal bridge; TD, temporal fossa dura; SOF, superior orbital fissure; V1, ophthalmic division of the trigeminal nerve; V2, maxillary division of the trigeminal nerve.

Figure 6 Intraoperative photographs of surgery for the paraclinoid aneurysm of the left internal carotid artery (continued). (A) After opening the dura mater along the sylvian fissure, the paraclinoid aneurysm compressing the optic nerve and intradural segment of the internal carotid artery is exposed. The dural ring and falciform ligament are resected. (B) After aneurysm clipping. C1 and C2, intradural segment of the internal carotid artery; C3, clinoid segment of the internal carotid artery; DR, distal dural ring; FL, falciform ligament; III, oculomotor nerve; ON, optic nerve; V1, ophthalmic division of the trigeminal nerve.

single neurosurgical procedure, “selective extradural anterior clinoidectomy,” without the transcavernous approach for treatments of aneurysms such as paraclinoid and basilar arteries and tumors in sphenoid bone-related structures.¹² Recently, techniques have been proposed to extensively expose the anterior clinoidectomy by the process of sectioning the periosteal fold in the SOF and minipeeling of the SOF.^{7,13,14} These techniques promote exposure of the entire ACP for its safety, with drilling under direct view. However, extradural anterior clinoidectomy through the trans-SOF approach needs extensive knowledge of the detailed anatomic structures in the SOF and CS, and microsurgical techniques including minipeeling of CS wall.

The SOF is a narrow bony cleft situated between the greater and lesser wings and body of the sphenoid bone.¹⁵ The SOF has a triangular shape with narrow

lateral part and wide medial part. The upper part of the SOF is formed by the lesser wing, ACP, and optic strut. The optic strut forms the inferolateral border of the optic canal and medial wall of the SOF. The SOF contains neurovascular structures such as the oculomotor nerve, trochlear nerve, ophthalmic division of the trigeminal nerve, abducens nerve, lacrimal nerve, carotid sympathetic nerves, and superior and inferior ophthalmic veins. The key anatomy is the membranous structures around the SOF and CS.¹⁶ The CS is located within the separate double dural layers, the periosteal layer in its medial wall and the meningeal layer (dura propria) in its lateral wall. The periorbita and periosteal layer of the middle fossa fuse together and form the periosteal bridge in the lateral part of the SOF. The lateral wall of the SOF is covered by the dura propria of the temporal fossa dura as the anterior part of the CS. The cranial nerves and venous plexus in the CS at the SOF are covered by inner reticular membrane, which is believed to originate from the epineurium of the cranial nerves.^{16,17} This semitransparent membrane separates the neurovascular structures in SOF and CS from the dura propria of the temporal fossa dura. Therefore, the dura propria can be peeled from the inner reticular layer without injuring the neurovascular structures in the SOF and CS.^{10,11} Our modified 3-D skull model precisely reproduced these membranous structures including the inner reticular layer in the CS and SOF. The manual process to make the model also facilitates anatomic understanding of the complicated membranous and neurovascular structures essential for peeling the dura propria from the lateral wall in the SOF.

The trochlear, frontal, and lacrimal nerves converge together and pass through the SOF, and the lacrimal nerve runs along the most lateral side. Therefore, the periosteal bridge should be divided using backward-curved scissors, and that incision should not exceed 4 mm to avoid injuring the lacrimal nerve.¹¹ The length of the incision of the periosteal bridge (meningo-orbital band) should be 3 to 5 mm.⁷ Cutting of the periosteal bridge is the one of the important steps, so should be exactly simulated using the 3-D skull base model. We recommend putting a small scale beside the SOF to measure the length to be cut. The next step is minipeeling of the dura propria of the temporal dura from the inner reticular layer of the SOF. We simulate this vital step using the modified 3-D skull base model, and we recognize that the peeling can be easily done from the side of the SOF to the FR. This peeling should be started from SOF,^{7,14} but peeling performed from the FR inferolaterally along the SOF superomedially is safer.¹³ Any definite conclusion about the better direction for the safe peeling of the dura propria from the SOF needs more study. After the minipeeling, the entire ACP is dissected out and can be safely drilled from its lateral side under direct view. The thinned bony

fragments can be removed from the thin periosteal membrane covering the clinoid space using the eggshell peeling technique.¹⁴

Dissection and drilling of the ACP under direct view is the great advantage of extradural anterior clinoidectomy via the SOF approach compared with selective anterior clinoidectomy, which eventually requires en bloc removal of the ACP. The working space in the epidural space during selective extradural anterior clinoidectomy is relatively narrow, but the minipeeling procedure of the dura propria of the temporal dura provides a wider epidural space for safe drilling of the ACP in the extradural anterior clinoidectomy via the SOF approach. Furthermore, opening of the orbital roof is not necessary. The illustrative case of paraclinoid aneurysm with compressed and eroded ACP demonstrates the provision of adequate working space for safe drilling of the ACP under the direct view. The disadvantage of the extradural anterior clinoidectomy via SOF approach is the greater risk to injure the neurovascular structures passing through the SOF during minipeeling. Therefore, training in the peeling technique in the SOF by cadaveric dissection or surgical simulation using the modified 3-D skull base model is highly recommended before clinical practice.

REFERENCES

- McAlea K, Forderhase P, Hejmadi U, Nelson C. Materials and applications for the SLS selective laser sintering process. In: Chartoff R, ed. *Proceedings of the 7th International Conference on Rapid Prototyping*. Dayton: University of Dayton; 1997:23–33
- Suzuki M, Ogawa Y, Kawano A, Hagiwara A, Yamaguchi H, Ono H. Rapid prototyping of temporal bone for surgical training and medical education. *Acta Otolaryngol* 2004;124:400–402
- Mori K. Three-dimensional temporal bone model for training in skull base surgery [in Japanese]. *Jpn J Neurosurg* (Tokyo) 2008;17:940–945
- Mori K, Yamamoto T, Oyama K, Ueno H, Nakao Y, Honma K. Modified three-dimensional skull base model with artificial dura mater, cranial nerves, and venous sinuses for training in skull base surgery: technical note. *Neurol Med Chir* (Tokyo) 2008;48:582–587; discussion 587–588
- Mori K, Yamamoto T, Oyama K, Nakao Y. Modification of three-dimensional prototype temporal bone model for training in skull-base surgery. *Neurosurg Rev* 2009;32:233–238; discussion 238–239
- Mori K. Dissectable modified three-dimensional temporal bone and whole skull base models for training in skull base approaches. *Skull Base* 2009;19:333–344
- Noguchi A, Balasingam V, Shiokawa Y, McMenomey SO, Delashaw JB Jr. Extradural anterior clinoidectomy. Technical note. *J Neurosurg* 2005;102:945–950
- Day JD, Giannotta SL, Fukushima T. Extradural temporo-occipital approach to lesions of the upper basilar artery and infrachiasmatic region. *J Neurosurg* 1994;81:230–235

9. De Jesús O, Sekhar LN, Riedel CJ. Clinoid and paraclinoid aneurysms: surgical anatomy, operative techniques, and outcome. *Surg Neurol* 1999;51:477–487; discussion 487–488
10. Dolenc VV. A combined epi- and subdural direct approach to carotid-ophthalmic artery aneurysms. *J Neurosurg* 1985;62:667–672
11. Dolenc VV, Roger L. *Microsurgical Anatomy and Surgery of the Central Skull Base*. Wien: Springer-Verlag; 2003
12. Yonekawa Y, Ogata N, Imhof HG, et al. Selective extradural anterior clinoidectomy for supra- and parasellar processes. Technical note. *J Neurosurg* 1997;87:636–642
13. Coscarella E, Bakaya MK, Morcos JJ. An alternative extradural exposure to the anterior clinoid process: the superior orbital fissure as a surgical corridor. *Neurosurgery* 2003;53:162–166; discussion 166–167
14. Froelich SC, Aziz KMA, Levine NB, Theodosopoulos PV, van Loveren HR, Keller JT. Refinement of the extradural anterior clinoidectomy: surgical anatomy of the orbitotemporal periosteal fold. *Neurosurgery* 2007;61(5 Suppl 2):179–185; discussion 185–186
15. Natori Y, Rhoton AL Jr. Microsurgical anatomy of the superior orbital fissure. *Neurosurgery* 1995;36:762–775
16. Kawase T, van Loveren H, Keller JT, Tew JM. Meningeal architecture of the cavernous sinus: clinical and surgical implications. *Neurosurgery* 1996;39:527–534; discussion 534–536
17. Ozveren MF, Uchida K, Aiso S, Kawase T. Meningovenous structures of the petroclival region: clinical importance for surgery and intravascular surgery. *Neurosurgery* 2002;50:829–836; discussion 836–837