Quantitative Analysis of Surgical Freedom and Area of Exposure in Minimal-Invasive Transcanal Approaches to the Lateral Skull Base

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Short running title

Surgical Freedom in Endoscopic Lateral Skull Base Surgery

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Conflict of Interest

The authors declare no conflict of interest.

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Key words

Surgical freedom; area of exposure; lateral skull base, minimal-invasive surgery, transcanal transpromontorial approach, infracochlear approach, suprageniculate approach

Abstract

Hypothesis: We aim to provide objective data regarding the area of exposure (AOE) and the surgical freedom (SF) offered by the transcanal approaches to the lateral skull base.

Background: Minimal-invasive transcanal lateral skull base procedures have been recently developed and their clinical feasibility demonstrated. The reduced access size requires careful analysis and selection of suitable cases, qualifying for a minimal-invasive approach.

Methods: We performed the mentioned approaches in standardized dissection using human whole heads. Surgical freedom is defined as the degree of movement liberty of the surgical instrument at predefined landmarks. We assessed SF at anatomical landmarks throughout the lateral skull base. Moreover, we measured the AOE, defined as the surface on the lateral skull base reached by every approach.

Results*:* We performed a total of 48 dissections under stereotactic image guidance in a total of 12 sides. The mean SF was assessed for the inferior petrous apex 602mm^2, for the geniculate ganglion 1916mm^2 and for the fundus of internal auditory canal 1337mm^2. The AOE was measured for the infracochlear approach 55mm^2, suprageniculate approach 67mm^2, transpromontorial approach 11mm^2 and for the expanded transpromontorial approach 93mm^2.

Conclusion*:* This study provides a quantitative description of minimal-invasive transcanal approaches to the lateral skull base. The AOE offered by the expanded transcanal transpromontorial approach is inferior but comparable to the reported AOE of transmastoidal approaches. The reported objective measurements may provide important information for future preoperative planning and patient counseling.

Introduction

Surgical approaches to the lateral skull base are most frequently adopted to remove tumors from this highly complex anatomical area. However, these approaches are commonly associated to a considerable procedural morbidity.[1] With the aim to reduce the size of the surgical access and related procedural morbidity, minimal-invasive approaches to the lateral skull base using a transcanal endoscopic technique were recently introduced. Three different routes to the medial part of the petrous part of the temporal bone were identified and described.[2] The infracochlear approach allows treating pathologies located below the cochlea with extension to the inferior petrous apex (e.g. cholesteatoma, cholesterol granuloma). The ossicular chain and the cochlea are entirely preserved. The suprageniculate approach exposes the geniculate ganglion and the middle fossa dura and is indicated to remove cholesteatomas or tumors extending into the superior petrous apex. This approach requires temporary removal of the incus. Performing an ossiculoplasty during the same intervention restores the hearing function. The transpromontorial approach to remove pathologies from the internal auditory canal (IAC) requires the sacrifice of the cochlea and therefore does not allow the preservation of hearing. Thus, indications are limited to patients presenting with a growing mass inside the IAC on serial MRI studies, most frequently vestibular schwannomas with concomitant profound hearing loss or debilitating vertigo preoperatively.[3-6] This intervention has, after its first implication in 2013,[3] already translated into clinics.[4] Most recently, an expanded transcanal transpromontorial approach was described, allowing the removal of Koos Grade II vestibular schwannomas. In this approach, the enlarged access allows a bimanual dissection under microscopic view.[5,6]

The indication to perform a minimal-invasive approach depends largely on the localization and the size of the pathology. In order to determine the feasibility and suitability of a minimal-invasive approach, the surgeon needs to know which structures may be reachable and what would be the area exposed by the surgical access under question. This surface may be measured and is named area of exposure (AOE).[7] Another important consideration in reducing the invasiveness of an approach is the degree of movement liberty of the surgical instrument in a narrow surgical corridor. This leeway on a predefined target can be measured and is described as surgical freedom (SF).[7] The knowledge of these quantitative measures is important to establish an adequate surgical plan preoperatively. In order to avoid the extremely time consuming intra-operative shift to open techniques, the correct identification of cases for minimal-invasive surgery is important.

A quantitative description of these novel approaches is not available in the literature. The aim of this study is to provide objective data regarding the AOE and the SF offered by the transcanal approaches to the lateral skull base. We hypothesize, that these measurements will improve the surgeon's ability to decide on the indications for a minimal-invasive approach and may therefore lead to improved patient counseling and intraoperative efficacy.

Material and Methods

Frameless stereotactic measurements of surgical freedom and area of exposure

The SF at any landmark is defined as the maximal working area reachable with the handle of a surgical instrument. The tip of the stereotactic pointer (200mm length) is placed on the target of interest and the handle moved to the extreme anterior, inferior, posterior and superior limit of the surgical access. The SF is then approximated by the sum of the areas of two side by side laying triangles reconstructed from the recorded three-dimensional (3D) positions of the pointer's handle as previously described.[8] This working area reflects the movement liberty of the instrument at a certain landmark. The measurements were taken under endoscopic view during the dissection studies (see below) after registration of high-resolution computed tomography (HRCT) image sets to an optical stereotactic navigation system (Cambar B1, Axios3D, Germany).[9]

The AOE is defined as the area reachable with the tip of the same surgical pointer for a specific approach at a predefined target region. In this work, the AOE is approximated by the sum of the areas of two triangles (three triangles in case of the suprageniculate approach) constructed from four positions of the pointer's tip (five positions in case of the suprageniculate approach). The positions correspond to the landmarks defining the border of the area at the level of the dura reachable in the target region using the chosen approach. The calculations of the SF and the AOE were done in MATLAB (The MathWorks Inc. USA).

Dissection procedures

We performed standardized cadaveric dissections on human whole head preparations under stereotactic image guidance. The endoscopic dissection was performed using 0°, 3 mm diameter and 14 cm length endoscopes connected to a high-definition camera system and monitor (Karl Storz, Tuttlingen, Germany). The microscopic steps were performed using a surgical microscope (Leica Microsystems, Wetzlar, Germany).

1. *Infracochlear approach:* First we performed a transcanal endoscopic access to the middle ear by creating a circular tympano-meatal flap with complete removal of the tympanic membrane. The enlargement of the external auditory canal (EAC) was standardized as following: Inferiorly starting from the emergence of the chorda tympani the bony annulus was removed until reaching the level of the jugular bulb (JB), which was skeletonized preserving

a thin bony cover. Then, the subcochlear canaliculus was identified and enlarged until exposing the internal carotid artery (ICA) anteriorly, representing the anterior limit of the approach. The bone between ICA, JVB and the basal turn of the cochlea was gradually removed and the inferior petrous apex accessed.

2. *Suprageniculate approach:* The Incus and the malleus were removed and a large atticotomy perfomed until exposing the aditus ad antrum and the lateral semicircular canal. Next, the cochleariform process was removed along with the tensor tympani muscle. The geniculate ganglion (GG) was identified and dissection pursued until reaching the greater superficial petrous nerve (GSPN). The bone covering the middle fossa dura was removed until exposing the dura from the GG and the GSPN anteriorly to the lateral semicircular canal posteriorly, the cochlear apex inferiorly and the tegmen tympani superiorly.
3. *Endoscopic transcanal transpromontorial approach (EndoTTA):* After removal of the stapes the spherical recess was identified, representing the most lateral boarder of the IAC. The basal turn was exposed as well as the cochlear apex with the modiolus. The bone between these three openings of the labyrinth was removed and the fundus of the IAC exposed. The dura of the IAC was skeletonized inferiorly and anteriorly until the deflection of the dura on the petrous bone. Thereafter we incised the IAC dura and identified the facial nerve (FN), cochlear nerve (CN), the inferior vestibular nerve (IVN) and the superior vestibular nerve (SVN).
4. *Expanded transcanal transpromontorial approach (ExpTTA):* The expanded approach to the IAC is based on an intercartilaginous incision between the tragal and the helical cartilage in order to perform an expanded canaloplasty.

The surgical microscope was used allowing bimanual dissection for the following steps: First a standardized canaloplasty was performed as following: exposure of the mastoid segment of the FN posteriorly, the temporo-mandibular joint (TMJ) anteriorly, the JB inferiorly and the middle fossa dura superiorly. The dissection of the IAC dura from the endoscopic transpromontorial approach was enlarged until complete exposure of the porus of the IAC.

Results

We performed a total of 48 dissections under stereotactic image guidance in cadaveric heads on a total of 12 sides (6 left, 6 right). The mean fiducial registration error was assessed 0.13 mm (± 0.06 mm). The identification of all anatomical landmarks and consecutive measurement of SF was possible in all sides. In Table 1, the mean SF is summarized for all assessed landmarks. Inside the EAC, SF was determined at the posterior notch (notch of Rivinus) and measured 3693 mm^2. SF at the promontory above the round window mas assessed 1565 mm^2 and after standardized canaloplasty 2023 mm^2. The SF for the infracochlear approach is plotted in Figure 1A. Landmarks measured for suprageniculate approach are shown in Figure 1B. The mean SF for the transpromontorial approach is illustrated in Figure 1C for the EndoTTA and in Figure 1D for the ExpTTA.

The mean AOE was measured at the end of every surgical approach either inside the petrous bone (infracochlear approach) or at level of the dura at the IAC, the middle or posterior fossa. For the infracochlear approach the surface between the ICA anteriorly, the basal turn of the cochlea superiorly, the JB inferiorly and the third portion of the FN posteriorly was measured 54.5 mm^2 (Figure 2A). Regarding the suprageniculate approach, five landmarks were used to assess AOE: the lateral semicircular canal postero-inferior, the middle cranial fossa dura posterior superior, the cochlear apex inferior, the superior boarder of the Eustachian tube anterior inferior and the middle cranial fossa dura anterio-superior. The mean measured value was 66.6 mm^2 (Figure 2B). The AOE at the fundus of the IAC (anterior, superior, posterior, inferior) was assessed for the exclusive endoscopic approach 11.1 mm^2 (Figure 2C) and for the expanded approach 92.8 mm^2 (Figure 2D). An additional measure at the porus of the IAC revealed an AOE of 108.4 mm^2. The assessed mean values along with standard deviation are summarized in Table 2.

Discussion

The surgical treatment of skull base lesions is complex and demands a high level of experience and surgical skills. The key to successfully treatment of the lateral skull base is doubtless the choice of the appropriate timing and modality for therapy. As most of the lesions encountered in this region are of benign nature it is of crucial importance not to cause excessive procedural morbidity and at the same time prevent a harmful progression of the disease. The clinical presentation along with the suspected nature of disease, growth over time on serial MRI scans and its extension on preoperative neuroradiological imaging guides the surgeon to establish a treatment plan and where appropriate to choose the surgical approach tailored to the disease. Indications for the described minimal-invasive procedures were previously described in clinical studies.[2,4,6] Alternatives to the surgical treatment would be to adopt a “wait-and-scan” policy or to perform stereotactic radiosurgery. In our opinion, the indication to a therapeutic intervention should be taken by an interdisciplinary board. In this controversy, it is crucial to provide objective data on the different approaches to support the choice of the surgeon. This is especially true in minimal-invasive procedures where the access is narrowed to a minimum and the surgeon works in a tunnel to reach the pathology without excessive removal of the temporal bone or craniotomy.

This study addresses the quantitative description of minimal-invasive approaches to the lateral skull base using frameless stereotaxy. This description is to our knowledge unique in the literature. The revealed measures of SF (Table 1) show a good maneuverability of the surgical instruments of generally more than 1300mm^2 at the level of the end of the instrument (200 mm) using a transcanal approach. This area represents the surface of a square with an approximated side length of 36mm. Considering the delicate movements required during ear and lateral skull base surgery, as well as the size of the anatomical structures, this mean area appears of considerable size. Probably, these favorable values are related to the direct angle of attack: every targeted structure by the described minimal-invasive approaches is in an almost direct line to the EAC. This is of high importance for several reasons: first, the surgeon may operate in direct vision of the lesion, second no dissection work around the corner is necessary and third, only minimal amendments to the temporal bone for access purposes are necessary. During pilot clinical experiences, this SF appears to be sufficient to treat lesions of the region[2,4,6,10]. One detail deserves separate mention at this point for safety reasons. The smallest measured value is the SF at the ICA during the infracochlear approach (475.2mm^2). This is clinically relevant, as in cases of injuries to the vessel the only option may be intraoperative packing, followed by endovascular management. In our opinion, the minimal-invasive endoscopic approach greatly benefits from the concomitant use of a stereotactic navigation system in order to provide additional spatial orientation, despite the reduced access size.

Our results concerning the AOE reveal valuable information to the surgeon, when planning a minimal-invasive intervention. For example, the AOE for the EndoTTA at the fundus of the IAC (11.1 ± 3.8mm^2) suggest, that removal of a tumor measuring more than 3x3mm is not reasonable, due to the limited size of the access to the fundus of the IAC. We have to consider, that the introduction of the endoscope (3mm diameter) into the IAC is not necessary at this point of the surgical procedure. For larger lesions a different approach (ExpTTA) may be adopted. Similar considerations apply for lesions of the superior and inferior petrous apex regarding the AOE of the suprageniculate and the infracochlear approach respectively (Table 2).

Siwanuwatn et al. analyzed working areas of the retrosigmoid, combined petrosal (Kawase combined with retrolabyrinthine approach), and transcochlear approaches to the petroclival region. Similar to our investigation they measured the AOE surface as a trapezium spanned on four anatomical landmarks. The measured AOE for the transcochlear approach was of 755.6 ± 130.1mm^2 for the petroclival and 399.3 ± 68.2mm^2 for the brainstem region. In contrast, measures for the combined petrosal approach were 354.1 ± 60.3 and 289.7 ± 69.9mm^2 respectively and for the retrosigmoid approach 292.4 ± 59.9 and 177.2 ± 54.2mm^2.[11] Comparing these values to our measurements, we observe a significant decrease in AOE using a minimal invasive approach. This emphasizes the importance of selecting the right cases for minimal-invasive procedures. The hereby-presented measurements may provide valuable information to the preoperative assessment and planning of the intervention. Of course, the measurements of the mentioned study[11] are not truly comparable, as they were taken at different and intradural anatomical landmarks (petroclival and brainstem versus landmarks inside the temporal bone in our investigation). However, the authors of the mentioned study[11] clearly draw a relationship between enlarged AOE and increase in procedural morbidity. Horgan and colleagues described this issue similarly for petrosal approaches (retrolabyrinthine, transcrusal with partial labyrinthectomy, transotic, and transcochlear)[12]. In this context, the limitation of the

AOE in the hereby-quantified minimal-invasive approaches is certainly the key to reduce surgical morbidity.

A recent study[13] assessed the AOE at the meatus of the IAC based on 3D reconstructions from CT scans. The revealed measures were for the retrolabyrinthine approach 140.30 ± 30.92mm^2, transcrusal 181.63 ± 38.55mm^2, and translabyrinthine 245.3 ± 44.27mm^2. In comparison, our results for the ExpTTA with an AOE of 92.8 ± 26.9 mm^2 for the meatus and 108.4 ± 65.3 mm^2 for the porus of the IAC are inferior but comparable. In contrast, the access size is considerably diminishes as assessed in a recently published pictorial review.[14]

Interestingly, a study by Tang et al. compared AOE and SF for the retrosigmoid approach and compared the use of the endoscope to the sole use of the microscope regarding the petroclival area.[15] The main findings were an increased visibility using the endoscope combined with a decreased maneuverability as compared to the microscope. The authors suggest an improved three-dimensional view of the local structures and emphasize on the interest in more minimalistic skull base procedures. In this context, the use of minimal-invasive approaches to the lateral skull base appears to be particularly beneficial. Advantages for the patients are minimized surgical amendments to the temporal bone and the absence of skin incisions (except for ExpTTA). We would concomitantly expect a reduction of total OR and recovery time, as well as minimized procedural morbidity. Yet, this needs to be proven in future large-scale cohorts. However, several clinical studies allowed to determine safety and efficacy of these new approaches.[2,4,6,10]

Conclusion

This study provides a quantitative description of minimal-invasive transcanal approaches to the lateral skull base. The AOE offered by the ExpTTA is inferior but comparable to reported AOEs of transmastoidal approaches. The reported objective measurements may provide important information for future preoperative planning and patient counseling.

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Tables

Landmark	**Working area (mm^2)**	SD (± mm^2)
Middle ear access		
Posterior notch	3692.5	1821.3
Promontory	1565.2	954.3
Infracochlear approach		
Promontory after canaloplasty	2022.9	997.4
Subcochlear canaliclus	1402.2	780.3
Internal carotid artery	475.2	234.3
Inferior petrous apex	602.1	508.4
Suprageniculate approach		
Cochleariform process	1896.3	1228.1
Geniculate ganglion	1916.9	1258.5
Transpromontorial approach		
Vestibulum	2076.2	995.8
Fundus of internal auditory canal	1337.3	603.1
Porus of internal auditory canal	1923.5	958.1

Table 1: Surgical freedom: Synopsis of surgical freedom for different anatomical landmarks from external to internal auditory canal. The mean working area is defined by the degree of movement liberty of the surgical tool at a defined landmark.

Approach	Exposed area (mm²)	SD (± mm²)
Infracochlear	54.5	28.4
Suprageniculate	66.6	16.8
Transpromontorial	11.1	3.8
Expanded transpromontorial	92.8	26.9
Porus of internal auditory canal	108.4	65.3

Table 2: Area of exposure as assessed for the 4 different minimal-invasive approaches to the lateral skull base. The mean surface measured reflects the area inside the petrous bone or at the level of the middle and posterior fossa dura respectively, exposable by the approaches.

Figure Legends

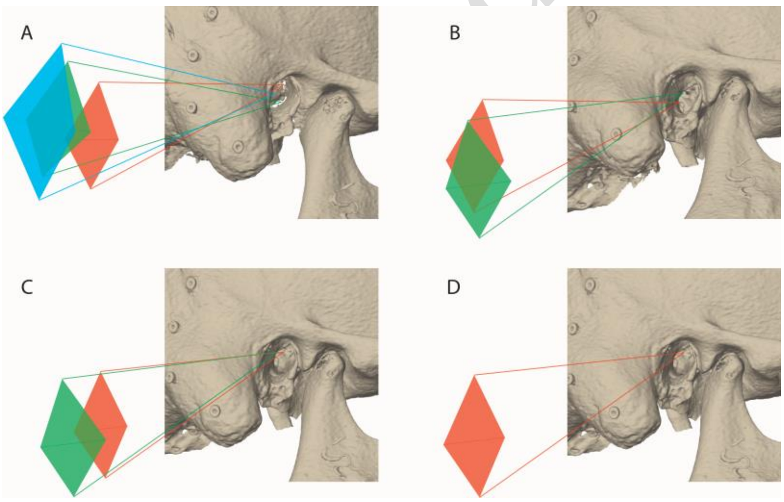

Figure 1: Plotting of surgical freedom for assessed landmarks per approach. A: infracochlear approach, blue: promontory, red: subcochlear canaliculus, green: internal carotid artery; B: suprageniculate approach: green: cochleariform process, red: geniculate ganglion; C: endoscopic transpromontorial approach, green:

vestibulum, red: fundus of internal auditory canal; D: expanded transpromontorial approach: red: porus of internal auditory canal

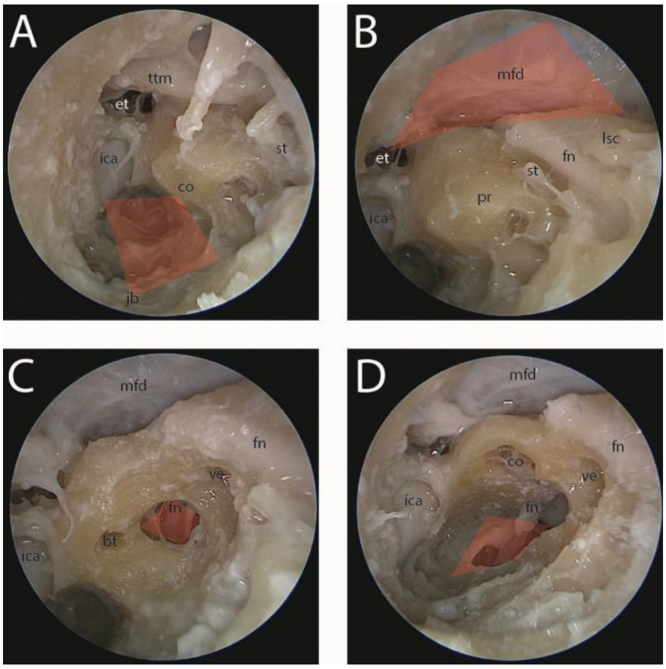

Figure 2: Area of exposure of minimal-invasive transcanal approaches to the lateral skull base. A: infracochlear, B: suprageniculate, C: transpromontorial and D: expanded transpromontorial approach.

ttm: tensor tympany muscle, ica: internal carotid artery, jb: jugular bulb, co: cochlea, et: Eustachian tube, st: stapes, mfd: middle fossa dura, lsc: lateral semicircular canal, fn: facial nerve, fn*: intrameatal part of facial nerve, pr: promontory, bt: basal turn of cochlea, ve: vestibulum