Petroclival meningiomas: an update on surgical approaches, decision making, and treatment results

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Object. Petroclival meningiomas remain a formidable challenge for neurosurgeons because of their location deep within the skull base and proximity to eloquent neurovascular structures. Various skull base approaches have been used in their treatment, and deciding which is the optimal one remains controversial. Attempts at achieving gross- or near-total resections are associated with an increased rate of morbidity and mortality. As adjunctive treatment options such as stereotactic radiosurgery have been developed and become widely available, there has been a trend toward accepting subtotal resections in an effort to minimize neurological morbidity. This paper reviews a recent series of patients with petroclival meningiomas and highlights current management trends and important considerations useful in surgical decision making.

Methods. The records of patients with large (> 3 cm) petroclival meningiomas surgically treated by the senior author over the past 5 years were reviewed. The clinical results are presented as examples of the surgical approaches available for approaching these tumors, and treatment options are reviewed.

Results. Of 196 meningiomas surgically treated during the study period, 8 lesions in 8 patients met the study criteria. Overall clinical results were excellent, with no death or major morbidity. Intracranial gross- or near-total resection (Simpson Grade 1, 2, or 3) was achieved in 5 patients (67%). New cranial nerve deficits occurred in 3 patients (37%) and were more common in patients in whom a subtotal resection was performed (2 of 3 cases). A variety of surgical approaches were used. Important considerations determining the best approach include the location of the tumor relative to the internal auditory canal, the presence of preoperative hearing loss, and the location of the tumor relative to the tentorium.

Conclusions. Achieving gross- or near-total resections of large petroclival meningiomas remains achievable and should be the primary goal of surgical treatment. A retrosigmoid craniotomy remains a workhorse surgical approach for most petroclival tumors of any size. Tumors that are medial to the internal auditory canal and span both middle and posterior cranial fossae are often best treated with a combined transpetrosal approach, which is especially true if there is a preoperative hearing deficit.

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KEY WORDS • microsurgery • petroclival meningioma • skull base surgery • stereotactic radiosurgery

PETROCLIVAL meningiomas present a formidable challenge for neurosurgeons because of their deep-seated locations and proximity to critical neurovascular structures. Advances in skull base approach, microneurosurgical techniques, and neuroimaging modalities together with intraoperative neurophysiological monitoring have led to a reduction in surgical morbidity and mortality rates. Despite advances and the usual benign history of lesions, the incidence of permanent cranial nerve deficits has been shown to vary from 20.3% to 76% in a number of series

(Table 1).^{2,4,6,12,33,38,39,41–46,50,55} Likewise, the rates of gross-total resection (GTR) in the same series vary widely from 20% to 85%, reflecting differing philosophies in management and surgical aggressiveness. Recently, most surgeons have tended to move away from radical resection to preservation of quality of life.^{4,12,26,33,34,38,39,42,50} Moreover, the availability of stereotactic radiosurgery (SRS),¹⁶ which has been associated with excellent tumor-growth control and progression-free survival rates with a long-term follow-up, has also affected treatment algorithms. Nevertheless, many skull base surgeons continue to advocate for aggressive resection whenever possible.¹⁵ In cases of smaller tumors, results typically are excellent, and often simple cranial approaches are adequate to ensure complete or near-total

Abbreviations used in this paper: GTR = gross-total resection; IAC = internal auditory canal; NTR = near-total resection; SRS = stereotactic radiosurgery.

TABLE 1: Reports in the literature of surgical outcomes in petroclival meningiomas

Authors & Year	No. of Patients	Mortality Rate (%)	Cranial Nerve Deficits (%)	GTR (%)
Al-Mefty et al., 1988	13	0	31	85
Sammi et al., 1989	24	0	70	71
Spetzler et al., 1992	18	0	39	78
Bricolo et al., 1992	33	9	76	79
Couldwell et al., 1996	109	3.7	33	69
Roberti et al., 2001	110	0.9	47	45
Little et al., 2005	137	0.7	22.6	40
Park et al., 2006	49	2	28.6	20
Bambakidis et al., 2007	46	0	30	43
Natarajan et al., 2007	150	0	20.3	32
Seifert, 2010	93	0	31	37
Nanda et al., 2011	50	0	32	28

resection (NTR).⁴ Larger tumors are much more difficult to treat and often require complex skull base approaches, many of which are rarely performed and are described using unclear terminology. Understanding the natural history, determining the surgical approach, and knowing the radio-surgical results is important in selecting the ideal treatment modality for petroclival meningiomas. In this context, we reviewed these issues and discuss the management of petroclival meningiomas by describing a small series of large tumors to demonstrate anatomical and clinical factors that are useful in treatment decision making.

Methods

We reviewed data obtained in patients who underwent surgical treatment of large petroclival meningiomas (defined as > 3 cm in any 1 diameter). The review encompassed the years of 2009–2013 to reflect the most recent treatment modalities in use for these lesions. All surgeries were by a single treatment team led by the senior surgeons (C.A.M. and N.C.B.). We excluded patients in whom neurofibromatosis Type 2 was diagnosed as these cases exhibit a unique set of clinical and radiological presentations.

Results

Of 196 meningiomas treated at the University Hospitals Case Medical Center during the study period, clinical results of 8 patients meeting the study criteria were included (Table 2). All patients had either progressive tumor growth or neurological symptoms necessitating microsurgical treatment. Overall, there were 6 male and 2 female patients. The overall mean age for all 8 patients was 55 years (range 15–75 years). The average maximal tumor diameter was 4.2 cm (range 3.2–5.5 cm). Surgical treatment was performed in all cases. Mean follow-up for this small series was 7 months (range 1–48 months). The approaches used included retrosigmoid ($n = 2$), orbitozygomatic ($n = 1$), a combined retrosigmoid and far-lateral approach ($n = 1$), and combined transpetrosal approaches

($n = 4$). Treatment was chosen primarily using an algorithm that includes assessment of preoperative hearing status and tumor location relative to the internal auditory canal (IAC) and to the tentorium (Fig. 1). There were no incidences of major neurological morbidity or stroke. One patient (Case 7) suffered a cerebellar hemorrhage postoperatively, without need for treatment, and made a full neurological recovery. New cranial neuropathies were present in 3 patients during the follow-up (37.5%). There were no incidences of postoperative infection or CSF leakage. Either a GTR or NTR was achieved in 5 patients. Resection was considered a GTR in cases of complete macroscopic tumor along with some dural coagulation and/or removal. An NTR was considered to correspond to greater than 90% resection shown on postoperative imaging and usually correlated to the surgeon's intraoperative impression that all macroscopic tumor had been removed. The results of GTR and NTR were thought to correspond to Simpson grade resections of 1–3. One patient (Case 3) presented with a large petroclival meningioma extending out of the jugular foramen extracranially, and, in this case, a GTR of the intracranial component was achieved. Subtotal resections (corresponding to obvious residual macroscopic tumor seen intraoperatively or greater than 10% residual tumor on imaging postoperatively) were performed in 3 patients. In each of these cases, the feeling of the senior author (N.C.B.) was that unacceptable neurological morbidity would result from GTR or NTR due to anatomical considerations present at the time of surgery. In these cases, subtotal resection was necessary because neurovascular structures were encased by tumor without a clear plane. All of these patients went on to receive SRS, which targeted the residual tumor, and tumor stability was shown on postoperative imaging at the limits of the mean follow-up of the study.

Illustrative Cases

Case 7

This 75-year-old woman presented with gait difficulty and episodes of vague alterations of consciousness.

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TABLE 2: Patients with symptomatic petroclival meningiomas measuring larger than 3 cm in largest diameter treated by the senior author over the study period*

Case No.	Age (yrs), Sex	Size (cm)	Clinical Presentation (grade)	Surgical Approach	Management	New CN Deficit
1	61, M	3.4 × 3.8	ataxic gait, facial weakness (2/6), hearing loss	combined transpetrosal	subtotal removal & SRS	IX, X, XII
2	56, M	4.6 × 1.5	hearing loss, gait unsteadiness	retrosigmoid	NTR	none
3	15, F	4 × 4	hemiparesis, dysphagia, tongue atrophy	combined retrosigmoid/far lateral	GTR intracranial	none
4	69, M	4 × 2	diplopia & headache	orbitozygomatic	subtotal removal & SRS	III/IV
5	50, F	2.8 × 3	diplopia & headache	combined transpetrosal	NTR	IV
6	67, M	4.4 × 3.4	headache, facial numbness	combined transpetrosal	subtotal removal & SRS	none
7	75, F	3.2 × 2.5	episodes of loss of consciousness	retrosigmoid	GTR	none
8	48, M	5.5 × 4.5	gait difficulty, diplopia, facial weakness, hearing loss	combined transpetrosal	GTR	none

* CN = cranial nerve.

Imaging demonstrated a petroclival meningioma located primarily lateral to the IAC, and there was evidence of enlargement on serial imaging (Fig. 2 left). A retrosigmoid approach was used for GTR (Fig. 2 right). Although the patient suffered a postoperative cerebellar hemorrhage, she tolerated it without deficits and did not require further procedures.

Case 5

This 50-year-old woman presented with diplopia and headache. The results of her examination were normal, although she complained of subjective diplopia. Imaging findings were consistent with a large petroclival meningioma spanning the middle and posterior fossae medial to the IAC (Fig. 3A and B). A combined transpetrosal approach was used for an anterior petrosectomy and posterior partial labyrinthectomy (Video 1).

VIDEO 1. Case 5. Video of a combined transpetrosal ap-

proach with anterior petrosectomy and posterior partial labyrinthectomy. Copyright Nicholas C. Bambakidis. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

Following NTR (Fig. 3C and D), the patient's preoperative trochlear nerve paresis worsened, but she otherwise has done well.

Case 8

This 48-year-old man presented with several months of progressive gait difficulty and weakness with dysphagia. On examination, he was found to have left hemiparesis, severe ataxia, hearing loss, abnormal eye movements consistent with impairment of cranial nerves IV and VI, and mild facial weakness. Imaging studies demonstrated a large left-sided petroclival meningioma with extension to the middle fossa and severe brainstem compression (Fig. 4A and B). The patient underwent a left-sided com-

FIG. 1. Algorithm illustrating important considerations in determining surgical approaches for the treatment of petroclival tumors. Anatomical location and hearing status are critically important.

FIG. 2. Case 7. Preoperative (left) and postoperative (right) axial images.

combined transpetrosal resection with both anterior and posterior petrosectomy (Video 2).

VIDEO 2. Case 8. Video of a left-sided combined transpetrosal resection with both anterior and posterior petrosectomy. Copyright Nicholas C. Bambakidis. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

Postoperatively, he did well with a GTR achieved and without new deficits (Fig. 4C and D).

Discussion

Natural History

As our study and others have demonstrated, large petroclival meningiomas are relatively rare lesions and have an unclear natural history. There is evidence to suggest that residual tumors are prone to recurrence, although it

FIG. 3. Case 5. Preoperative axial (A), preoperative coronal (B), postoperative axial (C), and postoperative coronal (D) images.

FIG. 4. Case 8. Preoperative axial (A), preoperative coronal (B), postoperative axial (C), and postoperative coronal (D) images.

is unclear if this recurrence is a result of selection bias or reflective of the biology of these tumors in all cases.²⁶ Untreated tumors seem to grow more rapidly when small or medium sized, although it may be presumed that large tumors have already been selected out for treatment due to their propensity for rapid growth or development of neurological symptoms.⁵⁹ Clearly, there are many cases in which asymptomatic small- or medium-sized tumors are followed conservatively, and the same can be said for large asymptomatic tumors in certain instances. The indications for surgical treatment remain documented growth and/or the development of neurological symptoms, and the indications remain dependent on patient characteristics, which may reflect surgical risk of morbidity.

Surgical Approaches

The preferred surgical approach for treatment of petroclival meningiomas is still controversial. The choice of approach depends on the location, extension, and size of the tumor as well as patient age, findings on evaluation of preoperative hearing and facial nerve function, and surgeon preference.^{1,15,33,38} Although various surgical approaches have been described in the literature, by and large 3 basic approaches are used most commonly: orbitozygomatic, transpetrosal (anterior, posterior, and combined), and retrosigmoid approaches.

Orbitozygomatic Approach. The orbitozygomatic approach is indicated for large lesions in the suprasellar, parasellar, and retrosellar areas, as well as for lesions extending into the cavernous sinus and the orbit. This approach allows excellent exposure of the anterior and middle cranial fossae, the area of the upper third of the clivus, and pos-

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terior fossa. Our previous cadaveric studies demonstrated that orbitozygomatic craniotomy allowed visualization of the tentorial notch and the contralateral upper quarter of the clivus compared with the retrosigmoid exposure.³²

Some authors use transzygomatic approaches as the only approach in patients with small- or medium-sized petroclival meningiomas involving the upper clivus or in combination with transpetrosal approaches in patients with tumors involving the upper and middle clivus and extending more than 2 cm above the dorsum sellae.³⁹ The transzygomatic approach has also been used with the retrosigmoid approach in the treatment of petroclival meningiomas because of their complementarity.^{4,47} It does provide an option in conjunction with staged orbitozygomatic and retrosigmoid approaches for treatment of paracentral petroclival meningiomas with large supratentorial extension into the parasellar region, cavernous sinus, or middle fossa.^{4,32} However, the staged orbitozygomatic and retrosigmoid approach requires separate procedures, incisions, and general anesthetic inductions and has not been found, in our recent experience, to be beneficial. It may be a good option in settings in which experienced neurotological expertise is of limited availability as temporal bone exposure is not required.

Anterior Transpetrosal (Kawase) Approach. In 1975, Bochenek and Kukwa⁵ described an extended middle fossa approach to the internal auditory meatus and the cerebellopontine angle. Kawase and colleagues^{27–29} described the anterior transpetrosal-transtentorial approach to aneurysms of the basilar tip and tumors of the petroclival and sphenopetroclival region. The Kawase approach is limited by the greater superficial petrosal nerve laterally, petrous ridge medially, mandibular nerve anteriorly, and IAC posteriorly. Variations to this approach have been well described.^{14,23} Kawase's approach provides an excellent exposure of the upper clivus and surgical freedom at the trigeminal porus.⁹ Risks of traction injury to the greater superficial petrosal nerve and temporal lobe venous injury must be considered.

The anterior petrosal approach is best suited for petroclival meningiomas medial to the IAC without extensive involvement of the posterior fossa.¹⁵ Our previous studies have demonstrated that Kawase's approach is suited for accessing middle fossa lesions with smaller petroclival components located above the IAC.⁹ Because larger tumors rarely are isolated to the middle fossa, we do not often use anterior petrosal approaches alone for these lesions. We instead commonly use combined transpetrosal approaches (as demonstrated in this series) for petroclival meningiomas that span middle and posterior cranial fossae. Risks to the temporal lobe can be mitigated if the approach is performed from the nondominant hemisphere.

Posterior Transpetrosal Approach. Posterior transpetrosal approaches provide a lateral operative corridor to lesions of the upper and middle clivus. Although many variations of this approach have been described in the literature, all are extensions of the basic mastoidectomy. In general, the posterior transpetrosal approach is divided into 3 variations: retrolabyrinthine, translabyrinthine, and transcochlear.³ Each differs in the extent of petrous bone

resection and has been well described.^{3,21,22,30,37,54,58} Progressively aggressive bone removal provides better anatomical exposure and increases surgical freedom. Nevertheless, the increase in exposure and surgical freedom comes at the expense of potentially increasing complication rates.

The retrolabyrinthine approach involves the smallest amount of petrous bone resection (Fig. 5). It avoids entering the labyrinth and skeletonizing the facial nerve, thus preserving hearing and facial nerve function. Although retrolabyrinthine approach is the safest method in terms of cranial nerve morbidity, it does not provide easy access to the central clival depression. If seventh and eighth cranial nerve function is to be preserved and if an anterior exposure to the brainstem is not needed, the retrolabyrinthine approach can be selected.⁵⁴

In the translabyrinthine approach, all 3 semicircular canals are completely removed and the lateral segment of the IAC is completely skeletonized (Fig. 6).^{21,30,37} Additional bone resection in the translabyrinthine approach increased access to the anterolateral brainstem and inferior clivus. However, the translabyrinthine approach sacrifices the labyrinth at the expense of hearing function. It is an option for increased exposure if the patient has little or no hearing.

The transcochlear approach requires resection of cochlea, division of the greater superficial petrosal nerve, and, in the transotic variation, exposure of the facial nerve in situ with occlusion of the auditory canal.^{22,25,58} The transcochlear approach provides the maximal exposure to both the petroclival surface and the anterior surface of the brainstem. However, it requires sacrifice of hearing and risks facial nerve function. Thus, this approach should be considered for patients who are already without functional hearing and who have severe preoperative facial weakness. Its current application is limited and it is rarely used.

Combined Transpetrosal Approach. The combination of anterior and posterior transpetrosal approaches further increases the exposure, while in some cases preserving hearing (Fig. 7).¹⁸ To preserve hearing, one can use a partial labyrinthectomy and partial apicectomy.^{19,20,51} A transcrural variant, which is thought to provide increased exposure and operative freedom to the central clival depression while minimizing cranial nerve morbidity, has been described.^{19,20,53} However, some researchers have noted that the dramatic change in exposure is due to performing the petrous apicectomy, instead of partial labyrinthectomy.^{7,51} In cadaveric models, little is achieved using a partial labyrinthectomy alone compared with a retrolabyrinthine approach.^{35,42} Furthermore, the partial labyrinthectomy also risks the loss of hearing. Therefore, some authors have used the combined petrosal approach, which incorporates the retrolabyrinthine approach and the anterior transpetrosal approach, to preserve hearing and to maximize the petroclival exposure by removing the petrous apex.¹¹ They have recommended the combined transpetrosal approach for patients with large petroclival tumors who have serviceable hearing and intact facial nerve function. We have found this modification

Fig. 5. Artist's drawings of the surgical view achieved using a standard retrolabyrinthine approach (**left**) and the added exposure gained with the transcranial approach (**right**). APC = ampulla of posterior canal; ASC = ampulla of superior canal; CC = crus commune; CN = cranial nerve; HC = horizontal canal; PC = posterior canal; SC = superior canal; SCA = superior cerebellar canal. Reproduced with permission from Journal of Neurosurgery Publishing Group. Courtesy of Barrow Neurological Institute.

Fig. 6. Artist's drawing showing progressive drilling of the temporal bone, identifying the 3 semicircular canals. Anterior to the facial nerve, the middle ear is entered through the facial recess. Reproduced with permission from Elsevier. Courtesy of Barrow Neurological Institute.

to be helpful and have used it with some regularity, one example of which is illustrated in our Case 5. A potential downside of these approaches is their time-intensive nature. We have found that performing the cranial work prior to beginning temporal bone drilling results in a significant reduction in the time required to obtain an adequate exposure.

Retrosigmoid Approach. Although the combined transpetrosal approach provides a wider surgical field, it also has several disadvantages, including increased risk of postoperative CSF leakage, damage to the facial nerve and functional hearing, temporal lobe retraction, increased risk of injury to the vein of Labbé, and increased operative time. In addition, the retrosigmoid approach can provide equivalent working area and angles of attack for petroclival lesions compared with a combined transpetrosal approach.⁵⁴ Furthermore, it has been shown that the retrosigmoid approach provides a significantly larger clival and brainstem working area than Kawase's approach.⁹ A suprameatal extension increases the degree of surgical freedom at the trigeminal porus and Meckel's cave.^{8,9}

The conventional retrosigmoid approach has been used for lesions with significant mass in the posterior fossa and involving the cerebellopontine angle.^{6,10,12,17,46,48} A modified approach, retrosigmoid intradural suprameatal approach, includes a retrosigmoid craniotomy and intradural drilling of the bone located above and anterior to the IAC.⁴⁹ The retrosigmoid intradural suprameatal approach is suitable for lesions mainly in the posterior

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FIG. 7. Exposure of the contents of the posterior fossa after combined approaches. Sequential movement of the operating microscope and judicious retraction of the sigmoid sinus posteriorly (**left**) or anteriorly (**right**) affords a view almost as complete as that afforded by its division. AICA = anterior inferior cerebellar artery; PICA = posterior inferior cerebellar artery. Reproduced with permission from Barrow Neurological Institute.

fossa with some extension through Meckel's cave into the middle fossa.^{49,60} However, it is difficult to remove lesions with a large extension in the middle fossa because this procedure makes the approach neither shallow nor broad.

radiosurgery

Stereotactic radiosurgery has come to play an increasingly important role in the management of petroclival meningiomas. Several recent studies on radiosurgical treatment of skull base meningiomas have shown promising results in terms of tumor control and neurological preservation at long-term follow-up.^{13,31,36,40,56,61,62} However, they did not clearly identify separately the results for the petroclival subgroup. Additionally, cranial nerve deficits still occur in up to 8% of patients.⁵⁷ Some authors have advocated staged SRS for patients with large tumors who are not surgical candidates.²⁴ Most data nearly entirely represent those derived from case series in which SRS was used to treat small- or medium-sized tumors, and data for patients such as those in the present series are extremely limited.¹⁶ Tumor recurrence rates might be influenced by less extensive resection,^{26,33} malignant histological results,¹² and cavernous sinus involvement.^{12,33} Although some authors have recommended SRS for treatment of residual tumor after maximal tumor resection,³⁸ we do not perform radiosurgery as a routine for every case with residual tumor. In our practice, the use of SRS is individualized and depends on several factors such as patient's age, residual tumor volume and location, and pathological characteristics. Nevertheless, we do believe that large tumors presenting with symptoms and/or serial growth represent a more aggressive subset of lesions and require close postoperative monitoring. In our series, every case of subtotal resection eventually required SRS, despite the relatively short mean follow-up period.

Treatment Planning

With time and experience, we have moved away from the aggressive combined transpetrosal approach toward a conventional retrosigmoid approach for the great majority of petroclival meningiomas, particularly for lesions that extend lateral to the IAC or those without a significant supratentorial extension.^{4,47} With larger tumors, combined transpetrosal approaches remain an important tool, as others have pointed out.^{11,33,39,51,52} It must be remembered that many factors that prevent GTR are independent of the particular surgical approach chosen or even of the surgical skill or experience of the treatment team. These factors have been well described and include cavernous sinus invasion, brainstem pial invasion, neurovascular structures encasement, and firm tumor consistency.^{12,33,38,39} Factors such as tumor location in relation to the IAC, involvement of one or both cranial fossae, and preoperative hearing functional status are critical considerations in determining the optimal strategy for treating these challenging lesions (Fig. 8).

Conclusions

Large petroclival meningiomas remain extremely challenging lesions to treat surgically. All skull base approaches remain options in treatment planning and can be accomplished safely. Overall results can be excellent with limited morbidity. In our opinion, the best approach provides the greatest degree of exposure to maximize the resection while minimizing the risk of surgical morbidity. We have found that careful consideration of the anatomical relationships of the tumor (particularly to the IAC and the extent of the tumor above or below the tentorium) to be extremely helpful in surgical planning. Hearing preservation is also important and can guide surgical decision

Fig. 8. Illustrated examples of petroclival tumor landmarks important in determining the best skull base approach to use in a given case. The anatomical landmarks of most importance are the IAC and tentorium, dividing the middle and posterior cranial fossae, shown here in axial (A) and coronal (B) views. For tumors predominantly lateral to the IAC (and then infratentorial), a retrosigmoid approach (C) is adequate. Tumors with a significant component medial to the IAC (D) may be better approached via a transpetrosal trajectory. Tumors spanning the middle and posterior cranial fossae (E) are best approached in combination, often with a transpetrosal combined approach or with two separate craniotomies (for example, retrosigmoid plus orbitozygomatic). Copyright Jennifer Kerbo. Published with permission.

making. As in all cases, the choice of exposure also must be tailored to the ability and experience of the surgical skull base team.

Disclosure

Dr. Selman has stock holdings in Osteoplastics and Surgical Theater.

Author contributions to the study and manuscript preparation include the following. Conception and design: Bambakidis, Xu, Karamelas, Megerian. Acquisition of data: Bambakidis, Xu, Karamelas, Megerian. Analysis and interpretation of data: Bambakidis, Xu, Karamelas, Megerian. Drafting the article: Bambakidis, Karamelas, Megerian. Critically revising the article: Bambakidis, Karamelas. Reviewed submitted version of manuscript: Bambakidis, Xu, Karamelas, Selman. Approved the final version of the manuscript on behalf of all authors: Bambakidis. Statistical analysis: Xu. Administrative/technical/material support: Karamelas, Selman.

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