Meningiomas of the Pediatric Skull Base: A Review

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Abstract

Pediatric skull base meningiomas are rare and complex clinical entities. Meningioma is a relatively uncommon brain tumor in children, and only ~ 27% involve the skull base. Some evidence suggests that these tumors are more likely to be atypical or malignant in children than adults. The absence of female preponderance in pediatric meningiomas is reflected in the skull base subpopulation. Skull base meningiomas in children are most likely to be found in the anterior or middle fossa base, or involving the orbit and optic nerve sheath. Petroclival, suprasellar/parasellar, cerebellopontine angle, cavernous sinus, and foramen magnum tumors are very rare. Meningiomas constitute a small proportion of reported cases of pediatric skull base pathology, and they are entirely absent from many case series. Initial gross total resection is consistently associated with superior outcomes. Surgical approaches to the pediatric skull base must take additional factors into consideration including relatively smaller anatomy, immature dentition, incompletely aerated sinuses and air cells, and altered configurations of structures such as the pterional bony complex. Multidisciplinary expertise is essential to optimizing treatment outcomes.

Keywords

- meningioma
- pediatric skull base
- review

Introduction

Meningiomas of the pediatric skull base present a host of distinct challenges, not the least of which is their relative scarcity, both by pathology and anatomical location. Careful analysis of the available data on this subject is therefore particularly important to optimize outcomes. Disease recurrence is especially pertinent in this age group; a large anterior skull base meningioma with 10-year follow-up is illustrated in ►Figs. 1 and 2. The modern neurosurgical literature on pediatric skull base tumors and pediatric meningioma was surveyed to assess optimum strategies for treatment.

Meningioma is a far more common diagnosis in adults than children. Pediatric meningiomas comprise < 5% of all pediatric brain tumors and < 2% of all meningiomas.^{1–3} A large modern case series found only 29 pediatric cases among 1,737 meningioma patients.⁴ This study and others¹ have suggested that pediatric meningiomas are more likely to be

atypical or malignant. However, a recent clinicopathologic analysis of 87 pediatric cases using revised World Health Organization (WHO) criteria found 71% WHO grade I, 24% grade II, and 5% grade III tumors, a distribution much more closely resembling that seen in adult meningiomas than had been previously reported.⁵ Pediatric meningiomas are thought to be more likely associated with genetic disorders such as neurofibromatosis type 2 (NF-2), Gorlin syndrome, or Rubenstein-Taybi syndrome.⁶

The well-known preponderance of females among intracranial meningioma patients is not observed in children; a much smaller sex imbalance is seen and tends toward males. This tendency may be more exaggerated in very young patients, as reflected in one case series of 24 infants with meningioma in which 17 (71%) were male.⁷ This study also found these tumors to be more likely intra-axial and less likely intraventricular or located in the posterior fossa when compared with older children.^{1,7} Meningiomas in older

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Fig. 1 An 8-year-old girl presenting with headaches was found to have a large anterior fossa mass. Gross total resection required two stages due to blood loss. Pathology showed malignant meningioma.

children are more likely to be intraventricular than in adults. Pediatric spinal meningiomas, although extraordinarily rare, are predominantly found in females (83%), as they are in adults.⁵

Similar to its representation within meningioma patients, the pediatric age group constitutes a minority of patients presenting with skull base pathology. A recent single-institution case series of 223 consecutive adult and pediatric patients undergoing skull base surgery for tumor or cerebrovascular disease found only 27 of 223 patients < 18 years of age.⁸ However, skull base approaches have been shown in multiple series to yield very satisfactory therapeutic and cosmetic results in this age group.^{8–12} Pediatric patients derive benefits from minimal brain retraction that are comparable with those for adults, although additional considerations regarding skull development must be accounted for when planning surgery.

Much of the understanding of the behavior of pediatric skull base meningiomas has been generalized from adult data.¹³ A retrospective study of 227 adult patients with skull base meningiomas, with a mean age at surgery of 57 years, found that advanced age was a risk factor for developing postoperative hydrocephalus.¹⁴ It is unknown whether or

Fig. 2 The patient in Fig. 1 subsequently underwent radiation therapy. Although there has been no disease recurrence, the postoperative course 10 years later has been complicated by visual loss, panhypopituitarism, and significant cognitive impairment.

how far backward this age-associated trend can be extrapolated. Hydrocephalus as a postoperative complication of meningioma resection is rarely reported in pediatrics.¹⁵

Methods

A PubMed query was performed for English-language articles published between January 1990 and April 2013 using the following search keywords in various combinations: *meningioma*, *skull base*, and *pediatric*. References from all selected articles were further examined for additional suitable studies. Special attention was given to articles describing technical operative considerations in the pediatric population.

Results

All studies have been retrospective. Pediatric skull base meningiomas are generally reported as subsets of meningioma or skull base series, or as individual case reports.

Pediatric Meningioma Reports

Two large modern clinical reviews of pediatric meningioma were published in 2011.^{1,16} Combined data from both studies regarding tumor location are summarized in ►Table 1. Because there is significant overlap between the two studies, their findings are very similar, although they merit individual discussion.

A review of 22 studies published between 1974 and 2008, which included 582 pediatric meningioma cases in which the

Table 1 The 994 pediatric meningiomas by location^a

Non-skull base location (%)	Skull base location (%)
333 cerebral convexity (33.5)	64 anterior/middle cranial fossa (6.4)
155 intraventricular (15.6)	53 sphenoid/clinoid (5.3)
104 falx/parasagittal (10.5)	52 orbital/optic nerve sheath (5.2)
19 posterior fossa (1.9)	27 petroclival (2.7)
32 tentorial (3.2)	22 foramen magnum (2.2)
11 intrasylvian (1.1)	21 cerebellopontine angle (2.1)
23 intraparenchymal (2.3)	20 suprasellar/parasellar (2.0)
5 intraosseous/epidural (0.5)	10 olfactory groove/ethmoidal (1.0)
Total: 682 (68.6)	4 cavernous sinus (0.4)
	Total: 273 (27.5)
39 spinal (3.9)	
	Unspecified location
	54 supratentorial unspecified
	44 infratentorial unspecified

^aCombined from Auguste and Rutka¹ and Kotecha et al.¹³

tumor site was adequately specified, identified 126 tumors in a skull base location.¹ The most common skull base sites were sphenoid (36 cases; 5.9% overall) and frontal and/or middle fossa (32 cases; 5.1% overall). Spinal meningiomas were excluded, although 12 foramen magnum lesions (2.0% overall) were counted. The most common tumor location overall was the cerebral convexity, representing 29.4% of cases. There were 44 tumors counted in an unspecified posterior fossa location, presumably including both the cerebellar convexity and cerebellopontine angle. Thirty additional tumors were listed as unspecified multiple sites.

A subsequent and somewhat larger meta-analysis¹⁶ included 35 case series published between 1989 and 2010, of which 12 studies covering 221 patients were included in the previously described review. This study included a total of 698 tumors in 677 patients and showed a very similar distribution of pathology despite the inclusion of spinal meningiomas. Cerebral convexity tumors accounted for 29.4% of cases. There were 199 cases of skull base meningiomas, of which anterior and/or middle fossa base were the most common (50 cases; 7.2% overall). Sphenoid and clinoid lesions were considered together and accounted for 30 cases (4.3%). There were 21 cerebellopontine angle tumors (3.0%), which were distinguished from other lesions of the posterior fossa.

An important conclusion drawn from this study was that, independent of tumor location, initial gross total resection was the most important factor predicting progression-free and overall survival. This finding had previously been established for other pediatric brain tumor types including ependymoma,¹⁷ high-grade glioma,¹⁸ choroid plexus tumors,¹⁹ and medulloblastoma,^{20,21} as well as meningiomas in adults.^{22,23} A significant limitation of this study was that the mean total follow-up time of patients was < 6 years.²⁴ Relapses in adult patients have been observed after ≥ 15 years, even following complete resections.²⁵

Several retrospective meningioma case series, mostly single institution, including significantly or exclusively pediatric patients have identified varying proportions of tumors within the skull base. One recent study, which was not included in the previously described review articles and whose specific focus was pediatric skull base meningioma, found 6 skull base meningiomas of 12 total pediatric meningioma cases between 1995 and 2010.¹⁵ This represents a higher proportion of skull base pathology than has been reported in most other studies. The one exception, showing an even higher proportion of skull base pathology, was a single series of 24 pediatric meningioma patients in which NF-2 was excluded and 17 skull base tumors were described.²⁶

Other case series show lower proportions of skull base tumors among pediatric meningiomas. These include 8 of 20 (including 4 of 5 patients with a diagnosis of NF-2),² 2 of 21,²⁷ 10 of 38,²⁸ and 4 (including the only patient with NF-2) of 11.³ A series of 72 pediatric meningiomas included 4 orbital and 11 supratentorial nonconvexity lesions.²⁹ In a series of 10 pediatric spinal meningiomas, 3 cases were at the C1–C2 level including the only patient in the series with NF-2.³⁰ The largest identified series specific to foramen magnum meningiomas in all ages

included 2 pediatric cases of 40.³¹ Various case reports have described more atypical presentations including a 2-year-old girl without a known genetic syndrome presenting with a WHO grade III meningioma in the cerebellopontine angle.³²

The association of NF-2 with meningioma is well characterized, with ~ 25 to 40% of NF-2 patients developing at least one meningioma.¹ Overall, 100% of cases of multiple meningiomas in pediatric patients have been associated with NF-2.³³ Meningiomas associated with NF-2 have been found to have higher rates of atypical and anaplastic grades, higher proliferative indices, and a greater tendency for brain invasion.³⁴

Meningiomas are also well known to be a potential delayed sequel of radiation. A comprehensive study of radiation-induced brain tumors following central nervous system radiation therapy for cancer in children reviewed the literature from 1960 to 2007.³⁵ There were 142 patients with presumed radiation-induced brain tumors reported over this span whose primary diagnoses included 97 primary intracranial tumors (of which none were meningioma), 44 hematologic malignancies (most commonly acute lymphocytic leukemia [ALL] with 35 cases), and 1 intracerebral arteriovenous malformation. The secondary-induced tumors included 33 WHO grade I meningiomas and 7 atypical meningiomas seen. Patients with secondary grade I meningiomas had been radiated at a median age of 5.4 years (range: 1–17 years) and had a median latency period of 13.7 years (range: 0.5–28 years). Among these patients, the most common primary diagnoses were medulloblastoma (14 patients) and ALL (7 patients). Patients with a secondary atypical meningioma had similar ages of radiation therapy (median: 5.1 years; range: 1–9 years), latency periods (median: 21.1 years; range: 8–63 years), and primary diagnoses (two medulloblastomas; no other diagnosis represented more than once). Radiation-induced meningiomas overall were found more often to be multifocal, with no specific propensity for the skull base or other locations. A similar large single-institution case series of second neoplasms following radiation therapy identified 24 cases, of which 3 were single WHO grade 1 meningiomas, 2 were multiple WHO grade 1 meningiomas, and none were atypical or high-grade meningiomas.³⁶ Of the two patients with multiple meningiomas, one had NF-2 and the other had Gorlin syndrome. NF-1 patients were excluded from this study.

Pediatric Skull Base Reports

Skull base tumors in children comprise a very heterogeneous spectrum of pathologies, both benign and malignant. Relatively common entities such as juvenile nasopharyngeal angiofibroma have a predilection for this age group. Sarcoma is typically the most common malignancy reported.³⁷ There are frequent associations with NF-2, Gorlin syndrome, and other congenital disorders. Most pediatric skull base clinical studies are single-institution retrospective case series, many of which do not include any patients with meningioma.

Skull Base Case Series Including Meningiomas

Meningiomas constituted at most a small percentage of skull base pathologies in all case series reviewed.

A case series including 55 patients treated between 1992 and 1999 by a dedicated multidisciplinary pediatric skull base team included 3 patients with a diagnosis of meningioma.⁹ Details of those patients were not further specified. Over this study period, 56 craniotomies were performed for skull base pathology of 678 craniotomies overall (8.3% of cases). The most commonly involved anatomical sites were mesial temporal lobe (13 cases), suprasellar region (10 cases), and brainstem (9 cases). The most common surgical approach was orbitozygomatic, which accounted for 26 cases. The most common pathologies were astrocytoma (13 cases) and craniopharyngioma and juvenile nasopharyngeal angiofibroma (6 cases each).

The largest single-institution pediatric skull base series included 112 patients undergoing endoscopic endonasal surgery for tumor resection between 1999 and 2011.³⁸ A total of 30 different pathologies were encountered, among which the most common were angiofibroma (23 cases), craniopharyngioma (16 cases), Rathke cleft cyst (11 cases), and pituitary adenoma and chordoma/chondrosarcoma (10 cases each). There was one orbital meningioma that was not included among the cases exhibiting recurrence but otherwise was not described in detail. Within this series, 93 total diagnoses (83%) had a benign histology.

Several other pediatric skull base series included only one meningioma case each. In a 20-patient series over 5 years, an optic nerve sheath meningioma with intracranial extension in a 12-year-old boy presenting with blindness and proptosis was treated with gross total resection via an orbitozygomatic osteotomy with orbital box reconstruction and no reported postoperative problems or adjuvant therapy.³⁹ A 19-year-old girl with a large petroclival clear cell meningioma (WHO grade II) extending from the cerebellopontine angle to the foramen magnum was 1 of 13 skull base cases in a series of patients treated via the posterior petrosal approach.⁴⁰ This patient underwent a combined left posterior petrosal, anterior petrosal, and far-lateral approach for subtotal resection due to brainstem adherence. The tumor residual was treated with postoperative radiation and was stable after 6 years. The patient experienced transient dysphagia that resolved completely, delayed cranial nerve VII palsy that resolved to a House-Brackmann grade 2, and worsening of ipsilateral sensorineural hearing loss. A third series of 67 pediatric skull base tumor patients over 6 years identified only one meningioma, although details of that case were not further described.⁴¹ The most common diagnoses in this series were craniopharyngioma (10 cases), sarcoma (9 cases), and chiasmatic glioma and juvenile nasopharyngeal angiofibroma (8 cases each).

A detailed single-institution series of 23 pediatric skull base tumor patients between 1998 and 2008 identified three cases of meningioma.⁴² The first was a diffuse central skull base tumor associated with NF-2 in a 4-year-old boy who underwent subtotal resection without adjuvant therapy; the patient experienced no deficits and the residual has been stable. The second case was an atypical meningioma of the cerebellopontine angle in a 7-year-old girl who underwent gross total resection via a translabyrinthine approach, complicated by House-Brackmann grade 2 facial weakness. There

were tumor recurrences at 2 and 4 years after initial surgery, treated with radiation and reoperation. The third case was a sphenoorbital meningioma in a 15-year-old girl that was treated with gross total resection via an orbitozygomatic approach with Le Fort 1 maxillotomy. Tumor recurrence 3 years after surgery was treated with radiation. Lansky Performance Scores were reported as 100 in patients 1 and 3, and 90 in patient 2. Three patients in this series, none with meningioma, developed postoperative hydrocephalus.

Another similar study encompassed 42 pediatric skull base tumors treated between 1992 and 2002, of which 2 were meningiomas.⁴³ The first case was a foramen magnum meningioma in a 13-year-old girl who underwent gross total resection without complication or adjuvant therapy. She was disease free 8 years later. The second case was a malignant meningioma of the middle cranial base in a 10-year-old girl who underwent subtotal resection followed by radiation therapy. There was subsequent disease progression, and this patient died 3 years after surgery. Association of these cases with neurofibromatosis was not specified.

Three recent single-institution case series on pediatric tumors of the cerebellopontine angle have been published. The first found 2 meningiomas of 29 total cases accumulated between 1988 and 2008.⁴⁴ The second series had only 1 meningioma of 26 cases between 2001 and 2012.⁴⁵ In both series, schwannoma was the most common diagnosis. Treatment results and comorbid genetic syndrome diagnoses for the meningioma patients were not separately described. The third study included 30 children with 33 cerebellopontine angle tumors, of which 6 were meningiomas treated between 1998 and 2003.⁴⁶ This study included six patients with a diagnosis of NF-2 who accounted for five of the six total meningiomas in the series. All tumors were resected via a retrosigmoid approach, and results were not separately specified for meningioma cases. An observation made from this series was that of the 33 tumors, 27 were left sided; this asymmetry has not been previously or subsequently described, and its significance is unknown.

Skull Base Case Series with No Meningiomas Reported

Numerous single- and multi-institution case series of pediatric skull base pathology have been published in which no meningiomas were identified.

A large single-institution consecutive case series¹⁰ spanning the years 1992 to 2005 included 35 pediatric patients with skull base pathology (of which 24 had been previously reported⁴⁷), identifying 13 cases of benign pathology (most commonly juvenile nasopharyngeal angiofibroma with 6 cases) and 22 malignancies (embryonal rhabdomyosarcoma with 6 cases). Twelve cases required complex reconstruction involving multiple specialists and/or surgeries. Another similar series¹² of 26 pediatric patients who underwent surgery at a different institution between 1993 and 1998 for skull base tumors identified schwannoma as the most common pathology with 7 cases; no other diagnosis was represented more than twice. A third institution reported 13 pediatric patients with skull base pathology⁴⁸ of 300 pediatric patients undergoing surgery with frameless stereotaxy between 1991

and 1996. The most common diagnoses found were low-grade astrocytoma with three cases, and two cases each of cranio-pharyngioma, pituitary adenoma, and fibrous dysplasia.

A very large multi-institutional review³⁷ spanning 1956 to 2000 collected 84 cases of pediatric anterior skull base malignancy in which craniofacial resection was undertaken. Among these cases, the most common diagnosis was sarcoma (27 high grade, 9 low grade). A subset of 19 of these cases had been previously reported,⁴⁹ in which there were 10 diagnoses of sarcoma. In two similar surgical approach-specific single-institution series, there were no meningiomas identified among 11 patients⁵⁰ requiring LeFort I osteotomy (8 of whom harbored angiofibromas) or 6 patients¹¹ undergoing orbitozygomatic craniotomy (3 for cranio-pharyngioma). Emphasis was placed on the importance of prefitting and drilling plates for later reconstruction prior to osteotomy to preserve maxillary position and dental occlusion.

In a series of endoscopic endonasal procedures for anterior skull base pathology in patients < 19 years of age, 25 cases were collected between 2000 and 2005.⁵¹ The most common pathologies identified were Cushing syndrome (four cases) and juvenile nasal angiofibroma and fibro-osseous lesions (three cases each). There were six malignant neoplasms and no meningiomas. Another literature review on endoscopic anterior skull base surgery in pediatric patients from 2010 identified no cases of meningioma.⁵² Endoscopic endonasal surgery is a well-described treatment option for meningiomas, including very large tumors, of the adult anterior skull base.^{53,54} A 2011 literature review of expanded endonasal endoscopic resection of anterior fossa meningiomas summarized results on 69 patients, of which none were pediatric.⁵⁵

Surgical Approaches to the Pediatric Skull Base

General

Many skull base approaches in neurosurgery have been adapted from techniques originally developed in pediatric craniofacial surgery, and thus they are well suited for pathologies such as meningioma in children.⁵¹ Epidemiologically, there are proportionately fewer skull base lesions overall in children than in adults.⁵⁶ A higher percentage of complete resection at initial surgery has been reported in children compared with adults, a finding attributed to better definition of tissue planes and a higher incidence of benign tumors.^{12,56} However, the potential need to stage procedures due to blood loss is greater in children.⁵¹

Several general anatomic considerations have been observed. The pterion is displaced forward in children relative to adults, meaning that a standard keyhole burr hole will enter the periorbital rather than the anterior fossa.⁹ Placing the burr hole 2 cm behind the pterion avoids this pitfall. The frontal sinuses are often not yet aerated in young children,⁵⁶ and the frontal and middle fossae tend to have fewer bony convolutions.⁹ Postoperative complications tend to be highest with parasellar pathology (e.g., cranio-pharyngioma), in which pituitary and hypothalamic injury can occur either transiently or permanently.

Reports of preoperative embolization of pediatric meningiomas are rare. A 2013 series of eight pediatric patients undergoing tumor embolization included a single meningioma case in a 16-year-old with an intraventricular tumor successfully embolized prior to surgical resection.⁵⁷ Very small children may present technical challenges regarding intravascular catheter size and maximum tolerable contrast dose that would apply to all endovascular procedures. Anterior skull base tumors with primary blood supply from the ethmoidal arteries may not be suitable for embolization. Hemangioblastomas and choroid plexus tumors are more commonly encountered pediatric intracranial tumors that undergo embolization.^{57–60}

Considerations in Anterior Skull Base Surgery

In addition to having immature frontal air sinuses, the supraorbital foramen/notch is absent in children < 8 years of age.⁹ Le Fort 1 osteotomy should be deferred if possible until permanent teeth have erupted. If necessary, the osteotomy is best placed at least 7 to 10 mm above the permanent teeth roots; multiple authors stress the importance of plating before downfracture.^{9,11,50,56,61} Orbitozygomatic craniotomy has been described as particularly advantageous in the resection of cranio-pharyngiomas, specifically in achieving adequate exposure of the superior third ventricle through the lamina terminalis or underneath the A1 segment of the anterior cerebral artery. Patients < 3 years of age were also observed to have a relatively less prominent sphenoid wing and flatter middle fossa that resulted in less additional bone drilling once the orbitozygomatic complex had been removed.⁹

Transsphenoidal and endoscopic approaches to the anterior skull base are appropriate for pediatric patients, with some cautions, and were described in detail in recent clinical reports of 25 patients⁵¹ and 133 patients.³⁸ Advantages include avoiding developing dentition and facial growth plates, as opposed to in traditional transfacial approaches. However, sphenoid sinus pneumatization is rarely adequate for surgical approach before ~ 3 years of age. A fully endoscopic transnasal approach is less traumatic to the nares than a speculum; alternatively, a sublabial incision can be used. A fully endoscopic approach is particularly advantageous in accessing ventral skull base anatomy such as the lower clivus and foramen magnum.⁵¹ Other advantages of these approaches not specific to children include better protection of the optic apparatus and pituitary, preservation of olfaction, and avoidance of brain retraction.

Considerations in Lateral Skull Base Surgery

Multiple approaches to the pediatric middle cranial base have been reported including frontotemporal craniotomy with orbital and/or zygomatic osteotomy as previously described.⁹ Temporal craniotomy with zygomatic osteotomy and/or anterior petrosectomy has been similarly reported.^{62–64} Although preauricular infratemporal approaches have been described,^{61,65} the effect of mandibular resection in children is not fully understood, and it has been recommended that resection or disarticulation of the mandible be avoided in this age group. The transsphenoidal approach has also been used to access the middle cranial base.^{12,56}

The role of the posterior petrosal approach in pediatric skull base surgery has been studied in detail.⁴⁰ This approach is very versatile for pathology involving the middle and posterior cranial fossae, and it can be combined with a supratentorial approach for even more extensive exposure. It preserves hearing and facial nerve function as well as key venous structures including the transverse and sigmoid sinuses and the vein of Labbé. The primary consideration in children is the working distance between the sigmoid sinus and the labyrinth. In cases of incomplete development and aeration of the mastoid, an insufficient window may be present. The medial access can be augmented in these cases with either a retrosigmoid dural opening or, if hearing preservation is not an issue, a translabyrinthine or transcochlear approach. Close examination of preoperative magnetic resonance and computed tomography imaging is central to appropriate approach planning in these cases.

Considerations in Posterior Skull Base Surgery

Immature aeration of the mastoid air cells is a primary concern in surgical access to the posterior skull base. The solid bone can make both drilling and identification of the labyrinth more difficult, although the resultant exposure has been described as requiring less retraction of neural structures than in adults.^{39,56} Other approaches described in children include retrosigmoid,^{66,67} translabyrinthine,³⁹ retrolabyrinthine,⁶⁸ transcochlear,⁶⁹ transcondylar,⁶¹ and transjugular.⁷⁰ The transcochlear approach requires facial nerve transposition and is associated with a higher risk of facial palsy compared with retrosigmoid or translabyrinthine approaches. An infralabyrinthine infracochlear approach to a petrous apex granuloma was described that successfully alleviated the patient's symptoms while preserving hearing.⁵⁶ Considerations regarding optimizing the surgical approach based on pathologic anatomy are analogous to those in adults.

Conclusions

Skull base meningiomas represent a very small subset of pediatric intracranial tumor pathology, and they require broad and specialized institutional capabilities for optimum treatment. Longer survival horizons in this patient population make the issue of disease recurrence particularly relevant. Broad consensus exists in the literature that patients of all ages who undergo initial gross total resection have significantly better progression-free and overall survival than those with an initial subtotal resection. Expertise regarding both skull base surgical approaches and developmental considerations in the immature skull is essential to optimize treatment outcomes. Multi-surgeon multidisciplinary teams may provide the best opportunity to achieve this convergence.

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