Pontine encephalocele and abnormalities of the posterior fossa following transclival endoscopic endonasal surgery

Clinical article

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Object. Transclival endoscopic endonasal surgery (EES) has recently been used for the treatment of posterior fossa tumors. The optimal method of reconstruction of large clival defects following EES has not been established.

Methods. A morphometric analysis of the posterior fossa was performed in patients who underwent transclival EES to compare those with observed postoperative anatomical changes (study group) to 50 normal individuals (anatomical control group) and 41 matched transclival cases with preserved posterior fossa anatomy (case-control group) using the same parameters. Given the absence of clival bone following transclival EES, the authors used the line between the anterior commissure and the basion as an equivalent to the clival plane to evaluate the location of the pons. Four parameters were studied and compared in the two populations: the pontine location/displacement, the maximum anteroposterior (AP) diameter of the pons, the maximum AP diameter of the fourth ventricle, and the cervicomedullary angle (CMA). All measurements were performed on midsagittal 3-month postoperative MR images in the study group.

Results. Among 103 posterior fossa tumors treated with transclival EES, 14 cases (13.6%) with postoperative posterior fossa anatomy changes were identified. The most significant change was anterior displacement of the pons (transclival pontine encephalocele) compared with the normal location in the anatomical control group (p < 0.0001). Other significant deformities were expansion of the AP diameter of the pons (p = 0.005), enlargement of the fourth ventricle (p = 0.001), and decrease in the CMA (p < 0.0001). All patients who developed these changes had undergone extensive resection of the clival bone (> 50% of the clivus) and dura. Nine (64.3%) of the 14 patients were overweight (body mass index [BMI] > 25 kg/m²). An association between BMI and the degree of pontine encephalocele was observed, but did not reach statistical significance. The use of a fat graft as part of the reconstruction technique following transclival EES with dural opening was the single significant factor that prevented pontine displacement (p = 0.02), associated with 91% lower odds of pontine encephalocele (OR = 0.09, 95% CI 0.01–0.77). The effect of fat graft reconstruction was more pronounced in overweight/obese individuals (p = 0.04) than in normal-weight patients (p = 0.52). Besides reconstruction technique, other noticeable findings were the tendency of younger adults to develop pontine encephalocele (p = 0.05) and the association of postoperative meningitis with the development of posterior fossa deformities (p = 0.05). One patient developed a transient, recurrent subjective diplopia; all others remained asymptomatic.

Conclusions. Significant changes in posterior fossa anatomy that have potential clinical implications have been observed following transclival transdural EES. These changes are more common in younger patients or those with meningitis and may be associated with BMI. The use of a fat graft combined with the vascularized nasoseptal flap appears to minimize the risk of pontine herniation following transclival EES with dural opening.

(http://thejns.org/doi/abs/10.3171/2013.12.JNS13756)

KEY WORDS • clivus • encephalocele • pons • posterior fossa anatomy • transclival endoscopic endonasal surgery • oncology

ENCEPHALOCELE is defined as an extension of intracranial structures outside the normal confines of the skull. Other than cases of congenital bone defects, encephalocele may occur postoperatively and is usually described following decompressive craniectomies. Dural closure and bone reconstruction following craniotomy for brain tumor removal prevent the development of encephalocele. Endoscopic endonasal surgery (EES) has been introduced as a treatment option for skull base tumors with favorable outcomes. Skull base reconstruction techniques following EES have improved significantly.

Abbreviations used in this paper: AC-B = anterior commissure-basion; AP = anteroposterior; BMI = body mass index; CMA = cervicomedullary angle; EES = endoscopic endonasal surgery; ICP = intracranial pressure; IQR = interquartile range.
with the advent of vascularized flaps that have greatly decreased the rates of CSF leak. However, there are few techniques described for primary dural closure or bone reconstruction of the skull base through the endoscopic endonasal route, and none of these can be used following extensive resections. We have observed rare postoperative skull base changes on imaging studies after EES for posterior fossa tumor resection, with transclival pontine encephalocele as the most impressive change.

Methods

Study Groups

With approval by the Institutional Review Board, we retrospectively reviewed the medical files and imaging studies of 103 consecutive patients with clival tumors requiring transclival EES and treated at the University of Pittsburgh Medical Center during the period from March 2003 to September 2012. Although immediate postoperative MRI studies were available in every case, we excluded from the study patients with less than 3-month postoperative MRI. Posterior fossa changes were evaluated on the 3-month postoperative and most recent MRI; the time the changes occurred and the progress of changes were studied on the follow-up MR images. Other than the 14 cases with posterior fossa changes that qualified for the study group (13 clival chordomas and 1 petroclival meningioma), the same morphometric parameters were evaluated in 50 patients without clival defects from the practice of the senior author as the anatomical control group; these individuals had small lesions of the pituitary fossa (pituitary microadenomas) with otherwise intact skull base bone anatomy. Potential risk factors were evaluated and compared between the chordomas in the study group and a control group that included 41 patients with the same pathology (clival chordoma) who underwent the same degree of clival resection via EES but did not show postoperative deformities of the posterior fossa. Petroclival meningiomas were excluded from the control group given the surgical philosophy of subtotal resection in this entity.

Morphometric Analysis of the Posterior Fossa

All of the postoperative changes of the posterior fossa were studied on serial midsagittal postoperative MR images (starting from the 3rd postoperative month) of T1-weighted sequences and evaluated with the same criteria. Four parameters were studied and compared in the two populations: 1) the pontine location/displacement, 2) the maximum anteroposterior (AP) diameter of the pons, 3) the maximum AP diameter of the fourth ventricle, and 4) the cervicomедullary angle (CMA).

Instead of the clival plane (given the postoperative absence of the clivus bone), the location of the pons was evaluated using a line drawn from the anterior commissure to the basion (Fig. 1). This line is not parallel and is slightly posterior to the normal clival plane; the angle between the anterior commissure-basion (AC-B) line and the clival plane was calculated in the anatomical control group (n = 50). From the AC-B line, we measured the distance of the pontine surface in the control group to estimate the normal location of the pons. From the same line, we evaluated the degree of pontine displacement in the study group as the perpendicular distance of the ventral pons from the AC-B line. The maximum AP diameter of the pons (labeled “a” on Fig. 1) was measured as the perpendicular distance of the ventral marginal edge of the pons from the ventricular floor line (the midsagittal tangent to the rhomboid fossa). The maximum AP diameter of the fourth ventricle (labeled “b” on Fig. 1) was measured as the perpendicular distance of the fastigial point of the fourth ventricle (labeled “F” on Fig. 1) from the ventricular floor line. The CMA was measured as the angle subtended by lines drawn parallel to the ventral surfaces of the medulla and upper cervical cord.

In the study group, we also examined the axial T2-weighted series at the level of the “herniated” pons to identify the presence of CSF in front of the pons.

Risk Factor Analysis

Age, sex, body mass index (BMI), extent of bone resection, intraoperative dural opening, postoperative CSF leak and lumbar drain placement, postoperative meningitis, degree of tumor resection, and reconstruction techniques were evaluated as potential risk factors between the study group and the risk factor control group. To achieve matching with our control group, we studied these potential risk factors between same pathologies (clival chordomas) of the same size. We measured the length of clival bone involvement in the study group and excluded from the control group chordoma patients with a smaller degree of clival resection. Also, from the available chordoma pa-
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tients without postoperative pontine encephalocele we excluded pediatric cases that underwent multiple surgeries, including cervicooccipital stabilization. Applying these criteria, the risk factor control group included 41 clival chordoma patients aged 18–88 years with at least 2-cm clival involvement (measured in the longitudinal diameter of the clivus) without pontine encephalocele after transclival EES. The study group for this analysis included only 13 chordoma cases (we excluded the single meningioma patient with postoperative pontine encephalocele).

Statistical Analysis

Variables were tested for normality prior to statistical testing. Univariate associations were determined using the Student t-test or the Wilcoxon 2-sample test, as appropriate, and results were presented as means ± SDs in the case of normally distributed continuous variables and as medians (interquartile range [IQR]) for continuous variables that did not follow a normal distribution. The chi-square test was used for categorical variables. To assess the strength of bivariate associations of nonnormally distributed variables, the Spearman correlation coefficient was calculated. A multivariable logistic regression model was also constructed to assess independent correlates of pontine encephalocele. Statistical significance was set at p < 0.05. All statistical analyses were conducted using Statistical Analysis Software (SAS) version 9.3 (SAS Institute).

Results

Study Group Characteristics

Among 70 consecutive clival chordomas and 33 posterior fossa meningiomas treated with transclival EES with at least 3-month postoperative MRI, 14 cases (13.6%) with postoperative changes of the posterior fossa anatomy were identified that were treated within a period of 5 years (August 2007 to June 2012). The initial observation of posterior fossa deformities was confirmed by objective measurements and morphometric analysis of the posterior fossa in every case. The cohort included 13 chordomas (18.6% among this pathology) and 1 meningioma (3% among posterior fossa meningiomas). All patients were adults with a mean age of 42 years (range 29–66 years). There was a male predominance (male to female ratio of 1.8:1). Eight cases were primary and 6 were previously treated. All chordoma cases had either intradural or extradural tumor extension, so that the clival dura was resected as part of the pathology.

Reconstruction of the Skull Base Defect

The routine multilayer method of skull base reconstruction following transclival EES includes the use of collagen matrix covered by regenerative tissue matrix, and/or fat graft, and/or a vascularized nasoseptal flap; the fat graft is placed under the flap to fill the clival defect in most of the cases in which both materials are used. Cases without a fat graft generally had a nasoseptal flap placed directly on the clival defect following an inlay of collagen. All the reconstruction materials are held in place either with polyvinyl alcohol sponges or with a Foley balloon catheter. Rigid reconstruction materials were never used in our practice as the wide exposures do not allow for wedging of rigid materials. The use of the vascularized nasoseptal flap has become routine in recent years in every case of intraoperative CSF leak, with impressive results in preventing postoperative CSF rhinorrhea.

Postoperative Imaging Findings

In the study group, the AP diameter of the pons exceeded the AC-B line in every case. The degree of displacement measured from the AC-B line ranged from 2.1 mm to 13.6 mm (Table 1). Three cases had a borderline pontine displacement of less than 3 mm, but the coexistence of an enlarged fourth ventricle or decreased CMA in these cases led to their inclusion. The AP diameter of the pons ranged from 18.6 mm to 32.9 mm. The AP diameter of the fourth ventricle varied from 8 mm to 21.3 mm. The CMA values ranged from 127° to 157° (Fig. 2 left). Four patients (28.6%) showed normal posterior fossa anatomy on the 3-month postoperative MRI and developed the aforementioned changes at a later time (varying from 5 to 11 months). In 8 patients (57.1%) the pontine displacement remained stable over time, while in 6 (42.9%) the pontine displacement further progressed (from 2 mm to 11.6 mm) during the follow-up period. The average follow-up period was 13 months (range 3–62 months). Clear evidence of CSF in front of the herniated pons was documented on axial T2-weighted MRI in 13 patients (92.9%).

In the anatomical control group, the ventral surface of the pons was posterior to the AC-B line in 48 cases; in 2 cases, the ventral pons was located anterior to the AC-B line. The distance of the pons from the AC-B line ranged from –2.1 mm to 6.3 mm. The average AP diameter of the pons was 23.4 mm (range 20.1–27 mm). The diameter of the fourth ventricle varied between 5.9 mm and 14.9 mm. The CMA ranged from 141° to 172°. The minimum and maximum values of the studied measurements in the control and study group are presented in Table 1.

Measurements of the angle between the clival plane and the AC-B line in the control group ranged between 2° and 16°, with an average of 9.1°, confirming that the AC-B line is always more vertical and closer to the pons than the clival plane and explaining the incidental finding of 2 cases in which the pons was reaching and slightly exceeding the landmark of the AC-B line. The comparison of posterior fossa morphometric parameters and the significance of observed differences between the control and the study group are presented in Table 1.

Potential Risk Factors

We reviewed the degree of clival resection in the study group and found that an extensive resection of the clival bone was used in every case. Limited preservation of the upper or lower margins of the clivus (dorsum sella in 3 cases and anterior foramen magnum in 7) did not prevent pontine encephalocele. The width of the bone resection reflected the distance between the paracilval carotid arteries in every case and was not found to be associated with the development of pontine encephalocele. It is also important
to note that in every case the clival dura was resected as part of the pathology. This did not reach statistical significance when compared with the control chordoma group, but that may be due to the small number of patients who do not undergo dura resection with this pathology.

Postoperative measurements of intracranial pressure (ICP) were not available in most cases. However, we evaluated the BMI within the study group, as a predisposing factor for occult intracranial hypertension. One patient (7.1%) was underweight (BMI < 18.5 kg/m²), 4 (28.6%) were of normal weight (BMI 18.5–24.9 kg/m²), 5 (35.7%) were overweight (BMI 25–29.9 kg/m²), and 4 (28.6%) were obese (BMI > 30 kg/m²). Assessing the association between BMI and the degree of pontine displacement (measured as the distance of the ventral pons from the AC-B line), a direct association was observed, but it did not reach statistical significance (r = −0.32, p = 0.27). Mean pontine displacement was slightly larger among patients with a BMI > 25 compared with individuals with a BMI < 24.9 (p = 0.07; Table 2). Although the p value was > 0.05 in this case, it is considered statistically borderline significant because of the small samples (5 vs 9 cases).

In addition to the aforementioned observations within the study group of 14 cases, we evaluated the age, sex, dural opening, lumbar drain placement, postoperative CSF leak, evidence of meningitis, degree of tumor resection, and reconstruction technique as potential risk factors among the chordoma cases (n = 13). Given the borderline
 significance of BMI in the degree of pontine herniation, we analyzed reconstruction techniques combined with BMI. Comparisons with the matching control group of 41 chordoma patients are presented in Table 3. The use of fat grafts as a reconstruction technique had a significant impact on preventing pontine encephalocele (p = 0.02). When analyzing the use of fat graft in different BMI categories, we found that this technique did not change the outcome in normal weight patients, but the lack of fat graft reconstruction in overweight/obese individuals with dural opening significantly predisposed them to develop pontine encephalocele (p = 0.04). Age was of borderline significance (p = 0.05), indicating that younger adults have a higher tendency to develop pontine displacement compared with elderly patients. Additionally, postoperative meningitis was significantly associated with the development of postoperative posterior fossa changes.

In multivariable logistic regression in the whole sample, none of the parameters evaluated reached statistical significance, with the potential exception of age, in which a borderline significant association was observed. Thus, adjusting for sex, BMI, length of bone resection, CSF leak, and total resection, each year increase in age was associated with a 4% lower odds of developing pontine encephalocele (OR = 0.96, 95% CI 0.92–1.00, p = 0.06). However, when analyses were restricted to individuals with dural opening, the use of a fat graft as a reconstruction technique was related to 91% lower odds of pontine encephalocele (OR = 0.09, 95% CI 0.01–0.77). Although effect modification by category of BMI was not observed, this was likely a result of the small sample size, as the magnitude of the fat graft effect appeared greater in the overweight/obese patient group.

Clinical Consequences and Treatment

None of the patients with postoperatively disfigured posterior fossa anatomy were symptomatic during a mean follow-up period of 13 months (range 3–62 months). One obese patient experienced recurrence of a transient sub-

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<th>TABLE 2: Comparison of pontine displacement between normal weight and overweight/obese patients</th>
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<th>TABLE 3: Comparison of potential risk factors of pontine encephalocele in chordoma patients between the case-control and study groups</th>
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* Values in bold are statistically significant.
† Fisher’s exact test.
‡ Measured on sagittal MRI, represents the length of clivus eroded by the tumor.
§ Measured on axial MRI, represents the distance of the paraclival carotid arteries.
jective diplopia that then resolved prior to shunt placement for documented increased ICP (performed to try to reduce the encephalocele; Fig. 2 right). Planned proton beam radiation was also withheld as a result of the herniation.

Discussion

The endoscopic endonasal approach has recently been used in the treatment of clival tumors with impressive resection rates for chordoma. For the endonasal treatment of clival chordomas and posterior fossa meningiomas, extensive clival resection is required to achieve negative margins and wide decompression or resection of the dural tail, respectively. Meningiomas inherently require dural opening, and intradural extension of chordomas or infiltration of the clival dura (intradural extension) necessitates a wide resection of the clival dura in most cases. Although direct duraplasty or primary dural closure and bone reconstruction of the skull base are not feasible with EES, in our experience, secondary reconstruction results in decompression and restoration of the posterior fossa anatomy in most cases (Fig. 3). However, in 14 cases, deformities of the posterior fossa anatomy were observed with the most common being the anterior displacement of the pons or pontine encephalocele. Typical reconstruction of transclival defects includes an inlay graft and extradural coverage with a pedicled mucosal flap with or without fat graft, with the fat graft placed under the pedicle flap when used together. Cerebrospinal fluid leaks following transclival approaches occur more often than following an endoscopic endonasal approach at other sites and may be a consequence of high-flow defects, ease of flap placement, large defect size, and obesity.

In addition to the impressive postoperative imaging findings we encountered, we have to stress that this is a retrospective study with potential limitations. We tried to avoid biases and achieve the best possible matched cases for controls. However, given the unclear origin of the described phenomenon, potential risk factors might be overlooked.

Imaging Changes of the Posterior Fossa

The parameters we present have never been described before in the setting of new postoperative changes. The CMA values have been studied to evaluate the amount of basilar invagination, atlantoaxial dislocation, and brainstem/medulla compression. According to Wang et al., the normal CMA values range from 139° to 175.5°, with an average value of 158.46°, in accordance with our finding in the control group. Cranio cervical junction pathologies, such as basilar invagination and atlantoaxial dislocation, compress the brainstem and medulla placing them in excessive kyphosis, which is recognized as a decreased CMA value on sagittal MRI. The cervicomедullary kyphosis noticed in our study group was a result of the anterior displacement of the ventral surfaces of the medulla and pons without any sign of compression or cranio cervical junction instability. Although these postoperative changes in the posterior fossa anatomy were impressive, they were all asymptomatic and identified as incidental imaging findings. Thus, in contrast to craniocervical junction pathologies, the decreased CMA value following transclival EES does not result in neurological injuries.

The impressive angulation of the basilar artery because of the herniated pons (as shown in Fig. 2 left) could theoretically precipitate an ischemic attack. So far, none of our patients have suffered any vascular complications, but the use of MR angiography to evaluate flow through the basilar artery, as well as cine flow studies, could be useful to evaluate these patients in the future.

Risk Factors for Pontine Encephalocele

Postsurgical encephaloceles have been associated with decompressive cranietomies and dural opening. Other than the dural and bone defects in these cases, increased ICP is an additional factor determining the degree of cerebral herniation. Transclival pontine encephaloceles have not been previously described. In our experience, this finding was associated in every case with extensive resection of the clival bone and dura. However, this same wide skull base exposure did not result in anterior displacement of the pons in most cases, and the cause of herniation is unclear. Traction, as a result of adhesions between the pons and the reconstruction material, is an unlikely mechanism given the presence of CSF between the pons and the reconstruction in 92.9% of the cases.

It would appear that, as with any meningocele or encephalocele, pontine encephalocele likely occurs in the setting of at least a transient increase in ICP. The greater impact of fat graft in patients with high BMI and the greater incidence following meningitis are both consistent with this theory. An elevated BMI is a significant risk factor for intracranial hypertension, as well as spontaneous and postoperative CSF leaks. Although BMI was not a risk factor in the overall comparison, in the subgroup of patients with dural opening and absence of fat graft reconstruction, increased BMI predisposed patients to the development of posterior fossa changes. Meningitis causes at least a transient increase in ICP and may also contribute to this phenomenon by creating adhesions between the
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pons and dura as a result of intense inflammation. Given the lack of symptoms, ICP was not measured in the majority of our patients; thus, the role of this factor is not clearly established. Finally, the relationship of age to the results is unclear, although perhaps age-related atrophy is responsible for this trend.

Fat graft may limit the occurrence by providing a buttress to counteract such increased pressures. Thus far, the use of a fat graft during EES was mainly indicated to prevent a CSF leak. The use of the vascularized nasoseptal flap has dramatically decreased the postoperative CSF leak rates. With the current data, we believe that the combination of a fat graft and a vascularized flap can preserve the position of the pons and prevent a CSF leak, especially in patients with BMIs ≥ 25. The bulk of the fat may provide more support than the flap alone, which may be too compliant to maintain a normal position in all patients.

Future Speculations on Endoscopic Skull Base Reconstruction

Although asymptomatic, the postoperative posterior fossa deformities of these 14 patients raise the question of whether a different skull base reconstruction technique following extensive transclival EES with clival dura resection would prevent these deformities and/or should be used. These deformities can impact the postoperative radiation field or even the ability to deliver safe radiation given the increased proximity of the brainstem to the tumor bed. In this cohort, planned radiation was only not applied in 1 patient due to an encephalocele; however, this patient had undergone a gross-total resection and the role of radiation in this setting is not clearly established. Although there are some techniques that have been described for primary dural closure or bone reconstruction of the skull base following EES, none of them can be used after extensive clival and dural resections. In our experience, primary duraplasty through the endoscopic en- donasal route is not feasible. During EES for large clival lesions, extensive skull base exposure is required and usually the paracaval carotid arteries are skeletonized. Placing a titanium mesh or other such rigid buttress between the exposed paracaval carotid arteries is not a reasonable technique for safe bone reconstruction. That risk, combined with the potential for recurrence in these tumors, obviates this option. A multilayer reconstruction using fat grafts and a vascularized mucosal flap appears to be the best option in the absence of a rigid reconstruction. One has to consider potential problems with the use of fat, such as mass effect on the pons or herniation out of the defect with resultant displacement of the vascularized flap. In the future, improved instrumentation with the ability to place sutures and perform a watertight dural closure may be beneficial.

Conclusions

Pontine encephalocele resulting in enlargement of the fourth ventricle, increased AP diameter of the pons, and kyphosis of the cervicomедullary junction has been observed following transclival EES. Extensive clival bone and dural resection are key factors and the degree of pontine displacement was directly associated with increased BMI. Overweight/obese individuals without fat graft reconstruction after dural opening are more vulnerable to develop pontine encephalocele. Younger patients and those who develop postoperative meningitis are more likely to present with these posterior fossa changes. Even though these impressive changes of the posterior fossa anatomy are asymptomatic, they raise the question of whether the current skull base reconstruction techniques are adequate. The use of a fat graft under the vascularized nasoseptal flap is the single factor that was significantly associated with prevention of pontine displacement, and is therefore recommended. Future innovations in EES and altered techniques in endoscopic skull base reconstruction are expected to prevent such abnormalities while restoring the posterior fossa anatomy.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Gardner, Koutourousiou, Fernandez-Miranda, Wang, Snyderman, Rohfus. Acquisition of data: Koutourousiou, Vaz Guimaraes Filho. Analysis and interpretation of data: Koutourousiou, Vaz Guimaraes Filho, Costacou. Drafting the article: Koutourousiou, Costacou. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Gardner. Statistical analysis: Costacou. Study supervision: Gardner.

References

9. Koutourousiou M, Gardner PA, Fernandez-Miranda JC, Pal-

Manuscript submitted April 15, 2013. Accepted December 30, 2013. Please include this information when citing this paper: published online February 7, 2014; DOI: 10.3171/2013.12.JNS13756. Address correspondence to: Paul A. Gardner, M.D., Department of Neurosurgery, UPMC Presbyterian, 200 Lothrop St., Ste. B400, Pittsburgh, PA 15213. email: gardpa@upmc.edu.