Planum-Clival Angle Classification: A Novel Preoperative Evaluation for Sellar/Parasellar Surgery

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Abstract

Objective Endonasal approaches are increasingly used to treat sellar pathologies, leading to increased interest in achieving maximal safe resection. We propose a tool—the planum-clival angle (PCA)—and explore its surgical implications for sellar pathology resections.

Design Retrospective analysis.

Participants Consecutive patients with pituitary lesions between 2003 and 2013.

Outcome Measures The PCA and suprasellar extension ratios; head position and extent of surgical resection.

Results We enrolled 89 patients (ages 21–88 years). There were 15 type A patients (17%), 13 with suprasellar extension (89%) and ratios between 0.12 and 0.70. There were 61 type B patients (70%), 49 with suprasellar extension (81%) and ratios from 0.09 to 0.66. Finally, there were 13 type C patients (13%), 10 with suprasellar extension (73%) and ratios from 0.21 to 0.76. Type B was treated with a sphenoidectomy and neutral head positioning, type A with 10 to 20 degrees of flexion and an additional posterior ethmoidectomy with or without posterior planum resection, and type C with 10 to 20 degrees of extension and an additional superior clival resection.

Conclusions Sellar anatomy and PCA influence the growth patterns of sellar lesions. Thus PCA should allow for better surgical planning and thereby improve surgical efficacy.

Keywords

- ▶ sella turcica
- ▶ pituitary adenoma
- ▶ transsphenoidal surgery
- ▶ planum sphenoidale
- ▶ clivus

Introduction

The sella turcica is a saddle-shaped depression located within the body of the sphenoid below the brain and in the center of the middle cranial fossa. It contains the pituitary gland and is surrounded by the sphenoid sinuses inferiorly, the tuberculum sellae and planum sphenoidale anteriorly, the cavernous sinus bilaterally, and the dorsum sellae and posterior clinoid processes posteriorly. It is

limited superiorly by the diaphragma sellae and the optic chiasm.¹

Sellar and suprasellar lesions represent up to 20% of primary intracranial lesions² with pituitary adenomas accounting for ~ 90% of those lesions. Pituitary adenomas mostly affect patients between the third and sixth decades of life. Recent studies have found the prevalence of pituitary adenomas to be three to five times higher than previously believed, with a cross-sectional prevalence of 94 cases per

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100,000.² Other less common sellar lesions include craniopharyngiomas, Rathke cleft cysts, and meningiomas.³

The transsphenoidal approach, first described by Schloffer in 1907 for resection of a pituitary adenoma,⁴ has been refined over the years. The development of the surgical microscope first and later the endoscope has led to improved surgical visualization with better illumination and magnification. These, combined with better imaging techniques⁵ and the publication of several detailed anatomical descriptions of the sella,⁶ have catapulted transsphenoidal surgery into the position of the gold standard for the surgical management of sellar lesions.⁷

Unfortunately, despite all of these technological advances, transsphenoidal surgeries remain risky with a 0.9% mortality rate.⁸ One of the main complications of sellar surgeries is a cerebrospinal fluid (CSF) leak. Endocrine complications such as diabetes insipidus and panhypopituitarism are seen in 17.8% and 19.4% of patients undergoing transsphenoidal surgeries, respectively. Other significant complications seen in 1 to 2% of surgical series include meningitis and injuries to the carotid arteries, hypothalamus, or optic apparatus.⁸ Inadequate or unnecessary exposure during pituitary surgeries may increase these risks.

Head positioning during endoscopic endonasal surgeries is of paramount importance for various reasons. Excessive head extension can lead the surgeon toward the anterior cranial fossa, whereas excessive flexion encourages a clival trajectory. Unrecognized and unintended surgical paths may result in unexpected outcomes and a marked increase in the risks of inadvertent CSF leak, as well as neural and vascular injuries with associated morbidities.⁹

Multiple studies have focused on creating new classifications of the sellar region to facilitate surgery, decrease mortality or morbidity, and improve total resection rates. These classifications, often due to their complexity, are difficult to apply in the clinical setting and therefore have mostly been relegated to the research arena.

In the present study we propose a simple classification, the planum-clival angle (PCA) classification. The PCA is based on standard preoperative imaging and should help surgeons avoid the common pitfalls of endonasal transsphenoidal surgeries. It is also designed to facilitate decision making in transsphenoidal surgery and help in selecting the appropriate head position for a safer surgical corridor and better visualization of sellar pathology. The result would be improved surgical efficacy that would maximize resection and minimize risks. We also hypothesize that “pre-pathology” sellar anatomy and PCA influence the growth pattern of sellar lesions, and the degree of suprasellar extension may be intimately related to the PCA.

Methods

Ethics approval for this study was obtained from the research ethics board at our institution. All consecutive patients with sellar pathology over the previous 10-year period (2003–2013) were identified from our neurosurgery patient database. From these patients, those with pituitary adenomas

were identified. We excluded patients with only computed tomography (CT) or only magnetic resonance imaging (MRI) images and patients whose surgery in the 10-year period was not a first-time procedure.

For the patients enrolled in our study, we obtained demographic data, pathologic reports, preoperative CT and MRI images, as well as radiologic and operative reports. The radiologic reports provided us with information on the orientation of the sella, as described by a radiologist not involved in the study. The sella was considered horizontal if it was described as flat, shallow, or horizontal. If the sella was described as vertical, we considered this to be a vertical sella, and if it was described as normal or no comments were made by the radiologist about the orientation, we considered it to be a normal sella. The operative reports were used to determine the head position, the extent of the air sinuses, and the skull base bony resection performed during surgery.

We also analyzed patients' midsagittal CT and MRI images. We calculated the PCA for each patient by measuring the angle between two lines: the first line parallel to the planum sphenoidale and the second line parallel to the posterior clival base (►Fig. 1). The posterior clival base was defined as the straight line running from the basion to the first curvature of the posterior clival cortex. The dorsum sellae was not chosen as a reference point because it can be distorted by sellar/parasellar pathology and would therefore confound analysis. The measurements were performed on the WebPACS imaging system using standard simple angle measurement tools in the midsagittal plane.

For each patient, we calculated the height of the intrasellar and suprasellar portions of the tumor. A clinoidal line between the anterior and posterior clinoid defined the upper limit of the sella. Perpendicular lines from the clinoidal line to the most superior and inferior aspects of the lesion were measured to obtain the suprasellar height and the intrasellar height, respectively. The suprasellar ratio was then calculated by dividing the suprasellar height by the intrasellar height.

We calculated the range of the PCA within each group (horizontal, normal, and vertical). Proportions, ratios, and means with their confidence intervals (CIs) were calculated based on a 5% margin of error (α of 0.05). Comparison

Fig. 1 Planum-clival angle (PCA) measurement.

between groups was calculated using the chi-square test of independence with a degree of freedom of 2 and a probability level (α) of 0.05. The correlation between the PCA and suprasellar extension for each PCA type was also calculated using the r correlation coefficient. All statistical analyses were performed with SAS v.9.1 (SAS Institute, Inc., Cary, North Carolina, United States) and Microsoft Excel.

Results

We identified 114 patients in our database; of these patients 89 met our inclusion criteria. All of these 89 patients had pituitary adenomas that were confirmed by pathologic reports. Of these 89 patients, 46 (52%) were male and 43 (48%) female. ►Table 1 lists the population characteristics. The age of the patients ranged from 21 to 88 years.

After calculating the PCA within each group (►Table 2), we found the PCA within the horizontal sella type (type A) to be ≤ 121 degrees; while for the normal sella (type B), the PCA ranged from 105 to 120 degrees, and for the vertical sella (type C), the PCA included angles ≤ 104 degrees.

The PCA was then used to make a three-type classification based on CT scan measurements (►Table 2). CT measurements were chosen as bony anatomy and better represented on CT scans compared with MRI. Type A PCA was defined as *horizontal sella* and included angles ≥ 121 degrees. Type B PCA, also referred to as *normal sella*, showed angles from 105 to 120 degrees. Type C PCA, described as *vertical sella*, included angles ≤ 104 degrees (►Fig. 2A–C).

Most of the patients in this study had type B PCA (►Table 3). Type A PCA was seen in 17% of our study population (15 patients). Type B PCA was found in 61 patients (69%). The remaining 13 patients were classified as having type C PCA and represented 15% of all enrolled patients.

When the suprasellar extension was analyzed (►Fig. 3), it was found that 13 type A PCA patients had lesions with suprasellar extension, which represented 87% of all type A PCA patients. There were 49 type B PCA patients with suprasellar lesion extension, which represented 80% of all type B PCA patients. Ten type C PCA (73%) patients had suprasellar extension. There was no statistically significant difference between these groups in relation to the number of patients with suprasellar extension ($p = 0.83$).

The suprasellar extension ratio ranged from 0.12 to 0.70 in type A PCA patients (mean: 0.43 ± 0.18 ; CI: 0.10). This value ranged from 0.09 to 0.66 (mean: 0.41 ± 0.14 ; CI: 0.04) in type B PCA patients and between 0.21 and 0.76 (mean: 0.53 ± 0.15 ; CI: 0.09) in type C PCA patients. There was no statistically significant difference between these ratios when type A was compared with the normal type B ratios ($p = 0.73$). However, the comparison of suprasellar ratios of type B versus type C PCA patients did reach statistical significance ($p = 0.005$).

The correlation between PCA and the suprasellar ratio was examined, and we found that the r coefficients for type A, B, and C PCAs were 0.45, 0.06, and 0.20, respectively, and the r^2 values were 0.20, 0.004, and 0.04 for types A, B, and C, respectively.

Based on the operative notes on the patients enrolled in this study, we found that type B lesions were treated with a standard sphenoidectomy and neutral head positioning. Type A lesions with an additional posterior ethmoidectomy with or without a posterior planum resection and 10 to 20 degrees of flexion, and type C lesions with an additional superior clival resection with 10 to 20 degrees of extension. These positions for surgical approaches are illustrated in ►Fig. 4.

Discussion

Multiple classifications have been created over the years to define the sella turcica's anatomy. In a study published in 2008, Zagga et al described the normal variants of the sella based on plain radiographs.¹⁰ Patients (228; 171 male and 57 female) with no evidence of sellar pathology were selected and grouped into three categories based on sellar fossa morphology (round, oval, or flat) and three categories based on sellar floor anatomy (concave, flat, or convex). The predominant shape of the sella turcica was oval (190 patients [83%]), followed by round (24 patients [11%]) and flat (14 patients [6%]). The results of this study are similar to those of a European study with 200 patients in which 58% of the patients had a concave sellar floor, 32.5% had a flat floor, and 9.5% had a convex floor.¹¹ In our study, we found a similar distribution with type B (normal sella) the most common type (69%); however, these studies of Zagga et al were based on plain radiographic imaging in the normal population, which may explain the slight difference between our results and theirs. Furthermore, their studies did not focus on the profound impact of sellar orientation/anatomy in preoperative planning with the aim of improving surgical safety and efficacy; consequently, we did not have data with which to compare our results.

A detailed sellar classification was proposed by Axelsson et al in 2004.¹² This was later used in a larger study by Alkofide.¹³ Of 180 individuals, Alkofide found that the morphology of the sella turcica was normal in shape in 67% of the study population. Variation in morphological appearance was present in 33% of the individuals. These findings are within the same range as our results. Although we found both studies useful for studying the growth and development of individuals with craniofacial aberrations and syndromes, they are

Table 1 Patient demographic data

Variable	Value ^a
Sex	
Male	46 (52)
Female	43 (48)
Age	
Distribution, y	21–88
Mean, y	53.2 $\pm$ 15.5

^aMean values are presented as the mean plus or minus standard deviation. The other values are presented as the number of patients (%).

Table 2 Classification of planum-clival angle type and angle with information on head positioning and bony resection required

PCA type	PCA measurement	Head position	Extent of bony resection
A: Horizontal sella	≥ 121	10–20 degrees of flexion	Standard sphenoidectomy and posterior ethmoidectomy with or without a posterior planum resection
B: Normal sella	105–120	Neutral head positioning	Standard sphenoidectomy
C: Vertical sella	≤ 104	10–20 degrees of extension	Standard sphenoidectomy and superior clival resection

Abbreviation: PCA, planum-clival angle.

more valuable in orthodontics than in neurosurgery. They also did not address surgical approaches to the sella.

A more clinically relevant anatomical classification of the sellar region, based on the extent of pneumatization of the sphenoid sinus, was proposed.^{14,15} The extent of pneumatization has a direct influence on the surgical exposure of the sella turcica. According to this classification, the three types of sphenoid sinuses are conchal, presellar, and sellar. The conchal sinus is associated with a sella completely surrounded by bone and is not exposed to the sphenoid sinus. The presellar sinus has the anterior half of the sella exposed to the sinus. The sellar sinus is totally exposed to the air due to the good pneumatization of the sinus. This classification focuses on pneumatization of the sphenoid sinus, which is an important surgical factor. However, these studies were mostly descriptive anatomical studies and did not discuss the impact of this change on the operative positioning or the extent of bony removal in resections of sella tumors.

Campero et al⁹ defined the external anatomical landmarks to help simulate the surgical intranasal trajectory. The speno-sellar point was described as the point corresponding to the intersection between a line crossing the sellar floor and another line crossing the sphenoid rostrum. The speno-nostril line was determined by joining the speno-sellar point with the anterior edge of the anterior nasal aperture. This simulated the ideal surgical trajectory. It was recognized that misalignment of the surgical pathway during transsphenoidal procedures requires readjustments, increases the length of the procedure, and is likely to lead to increased complications. This is similar to our recommendations based on PCA measurements. Campero et al identified the importance of head position in transsphenoidal surgery; however, in their study there was no clear classification or exact recommendation for the head's position. Furthermore, they did not address the extent of bony resection.

Fig. 2 Illustrations of the three planum-clival angle types. (A) Type A (horizontal sella). (B) Type B (normal sella). (C) Type C (vertical sella).

Table 3 Distribution of planum-clival angle types in the patient population

PCA type	No. of patients (%)
A	15 (17)
B	61 (69)
C	13 (15)

Abbreviation: PCA, planum-clival angle.

Our investigations reveal that type B PCA (105–120 degrees) is the most common type (69%), typically requiring neutral head positioning with a standard sphenoidectomy without any further removal of bone from the skull base. This should be sufficient to adequately expose any pathology encountered with a normal sella. Such knowledge—especially preoperatively—may limit unnecessary bony removal that could lead to increased postoperative complications.

Type A PCA, defined as a wider PCA angle (≥ 121 degrees), is associated with a more horizontally oriented sella. This was seen in 17% of our study population (15 patients). Due to this sellar orientation, these patients needed different surgical positioning with 10 to 20 degrees of head flexion. They also required an additional posterior ethmoidectomy, with or without resection of the posterior planum, if there was

Fig. 3 Planum-clival angle (PCA) type with total number of patients per group and number of suprasellar extensions.

suprasellar extension. Knowing this preoperatively would be helpful in counseling patients about postoperative risks because these patients require more air sinus dissection and may have a higher rate of CSF leaks. Additionally, this would help achieve adequate surgical exposure, which may allow better tumor removal.

Type C PCA, defined as a sharper PCA angle (≤ 104 degrees), is associated with a more vertically oriented sella. In our study, this situation was rare and comprised only 13 patients (15%). Patients with this anatomical variant require 10 to 20 degrees of head extension and additional resection of the superior portion of the clivus to access the sellar floor,

Fig. 4 Lateral view head positioning based on the three planum-clival angle subtypes. (A) Type A (horizontal sella) with 10 to 20 degrees of flexion. (B) Type B (normal sella) with neutral positioning. (C) Type C (vertical sella) with 10 to 20 degrees of extension.

especially with lesions. This is the opposite of type A, and knowing this preoperatively would help shorten the duration of surgery by providing easier access to the tumor. We believe this would improve patient safety and reduce postoperative complications. Although we did not empirically assess the ease of intraoperative access for these patients, our conclusions on accommodating for the position of the head in the different PCA types are based on reviews of patients' operative notes.

In our institution, a standard sphenoidectomy would involve placing the patient in a supine position, setting the head in a fixation system, preparing the nasal passage and middle turbinate using Xylocaine/lidocaine for vasoconstriction, excising the middle turbinate, identifying the sphenoid ostium (~1.5 cm above the roof of the choana), detaching the posterior nasal septum from the sphenoid rostrum (using a microdrill with a cutting burr to create an anterior sphenoidotomy, which is then expanded circumferentially using bone punches or a microdrill) to expose the sphenoid rostrum, and finally removing the sphenoid rostrum in fragments.

A 2013 analysis of sphenoid sinus anatomy and its relation to suprasellar extension suggests that particular anatomical factors of the sphenoid sinus prevent tumor expansion into the sphenoid sinus and in doing so direct tumor expansion into the suprasellar space.¹⁶ Ramakrishnan et al found that their patients with suprasellar extension (71 of 106 [67%]) had significantly greater intersinus septum width and also tended to have two or more sphenoid partitions.¹⁶ The authors suggest that their findings may help predict the likelihood of suprasellar growth and compression of the optic apparatus in patients presenting with sellar masses, thus having an impact on the decision for early surgical management. Unfortunately, they did not describe the suprasellar extension in relation to the sellar orientation, and it is thus difficult to compare their findings with ours.

Tumors in the sella have different degrees of suprasellar extension. This may not always depend on the tumor size. In fact, this may be more closely related to the planum-clival angle and the sellar orientation. In our study we found that a higher proportion of patients with type A had suprasellar extension (87%), followed by type B patients (80%) and then type C patients (77%). These values are comparable with those reported by Ramakrishnan et al where 67% of patients had suprasellar extension¹⁶ and values reported by Zada et al where 80% of patients had suprasellar extension of growth hormone-secreting and nonfunctional pituitary adenomas.¹⁷ We expect that this is related to the anatomical orientation of the sella. In type A, the sella is more horizontal, and even small tumors would more likely have suprasellar extension compared with type C where the sella is deep and the tumor would need to reach a larger size to show suprasellar extension. When we examined this phenomenon, we did not find these differences to be statistically significant ($p = 0.38$); this may be related to the fact that we have a small number of patients with type A and C and that this study was not designed with the power to reveal this element. More patients are needed to show this statistically.

When we examined the suprasellar extension ratio within each group and compared it among the groups, we found that the suprasellar ratios of type B versus type C PCA patients were statistically significant ($p = 0.005$). This result indicates that in patients with a vertical sella there is a statistically significant difference in suprasellar ratio compared with patients with a normal sella. This information is in keeping with our finding of the least amount of suprasellar extension in type C PCA patients. Such differences were not present between the suprasellar ratios when type A was compared with the normal type B ratios ($p = 0.73$).

Correlation data revealed that type A patients were the only patients with a higher correlation between PCA and the suprasellar ratio ($r = 0.45$), compared with type B ($r = 0.06$) and type C ($r = 0.20$) patients. As expected, because most patients had a normal type B sella, the correlation between PCA and suprasellar ratio was reduced because there was a wider variation in levels of suprasellar extension with similar normal type B PCAs. Nevertheless, type A PCA had the highest correlation value followed by type C.

An important limitation of this study is that it is a retrospective and performed in one center. This may limit the external validity of these results. However, the pituitary adenoma patients involved represent a wide array of demographics, which is reassuring for the usefulness of the PCA. Because the results have yet to be validated extensively, it is even more important to proceed with a prospective study to validate the use of the PCA in preoperative planning, with measurements of ease for intraoperative access in patients with sellar lesions. It is also critical to explore the external validity of this measurement by having the measurements performed by blinded analysts not immediately involved with the study. This study was not designed with the power to determine significant differences in suprasellar extension ratios, so further studies should consider this in the study design to allow for better validation of this measurement tool. Also, the number of patients with type A and C PCAs were much smaller than those with type B PCAs. Further studies should consider this imbalance when creating patient sample sizes and in statistical analyses. Our next step will be to initiate a large prospective study to confirm the value of this new preoperative assessment tool.

Endonasal transsphenoidal surgeries are quickly becoming the standard of care for surgical management of most sellar/parasellar lesions. We believed it is important to find a simple way to facilitate preoperative evaluation, especially in relation to head positioning given its critical role in maximizing exposure. Our PCA classification has been designed with this goal, with hopes that it will help achieve maximal safe sellar/parasellar lesion resection (especially for patients with pituitary adenomas) and have a positive impact on surgical decision making, leading to better patient outcomes. Of course, we are not recommending that this classification system supplant the use of image guidance. Instead, it is to serve as another tool to assist with preoperative planning of the surgical approach and can be adjusted as needed with findings on neuronavigation and image guidance.

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