The Extended Nasoseptal Flap for Skull Base Reconstruction of the Clival Region: An Anatomical and Radiological Study

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Abstract

Objective Reconstruction of large clival defects after an endoscopic endonasal procedure is challenging. The objective is to analyze the morphology, indications, and limitations of the extended nasoseptal flap, which adds the nasal floor and inferior meatus mucosa, compared with the standard nasoseptal flap, for clival reconstruction.

Design Twenty-seven sides of formalin-fixed anatomical specimens and 13 computed tomography (CT) scans were used. Under 0-degree endoscopic visualization, a standard flap on one side and an extended flap on the other side were performed, as well as exposure of the sella, cavernous sinus, and clival dura mater. Coverage of both flaps was assessed, and they were incised and extracted for measurements.

Results The extended flap has two parts: septal and inferior meatal. The extended flaps are 20 mm longer and add 774 mm² of mucosal area. They cover a clival defect from tuberculum to foramen magnum in 66.6% cases and from below the sella in 91.6%. They cover both parasellar and paraclival segments of the internal carotid arteries. The lateral inferior limits are the medial aspect of the hypoglossal canals and Eustachian tubes. CT scans can predict the need or limitation of an extended nasoseptal flap.

Conclusions The nasal floor and inferior meatus mucosa adds a significant area for reconstruction of the clivus. A defect laterally beyond the hypoglossal canals is not likely covered with this variation of the flap. Preoperative CT scans are useful to guide the reconstruction techniques.

Keywords

- ▶ cerebrospinal fluid leak
- ▶ clival reconstruction
- ▶ endoscopic endonasal
- ▶ nasoseptal flap
- ▶ skull base

Introduction

The nasoseptal flap was described by Hadad et al in 2006 for skull base reconstruction, and its use has dramatically reduced the incidence of cerebrospinal fluid (CSF) leak after endoscopic extended skull base approaches, from 20 to 30% to less than 5%.^{1,2} The standard incisions of the nasoseptal flap

are designed in a way to add the majority of the septal mucosa to the flap excluding the olfactory mucosa superiorly. The inferior incision is classically performed at the junction of the septum and the nasal floor. If an extended nasoseptal flap is intended, the inferior incision can be performed more laterally including the mucosa of the floor of the nasal cavity and inferior meatus.

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The standard nasoseptal flap has been shown sufficient to cover the defect after anterior cranial base endoscopic resection.³ However, in some cases, the anterior orbit-to-orbit defect can present a limited coverage. The extra width gained with the incorporation of the nasal floor mucosa to the flap can help to increase the area of contact between the flap and the orbit.

Reconstruction of the clival region is complex, varies greatly with different approaches, and has been less studied.⁴ The extension of the flap laterally to the nasal floor might add a critical reconstruction surface to reach the foramen magnum.

The aim of this study is to describe in detail the extended nasoseptal flap and its potential indications and limitations for clival reconstruction.

Methods

Dissections

Twenty-seven sides of 14 anatomical specimens were used for dissections. One specimen was divided in the sagittal plane and was used for dissection of the nasoseptal flap macroscopically. Twelve specimens had a standard nasoseptal flap dissected on one side and an extended nasoseptal flap on the other side, being right- or left-side elected in a random fashion to avoid differences due to the dexterity of the surgeon. One specimen had only one side available for complete dissection due to previous sinonasal surgery, and an extended flap was performed in the contralateral side. A total of 12 standard flaps and 13 extended nasoseptal flaps were dissected using endoscopic endonasal technique. To mimic the surgical technique, an electrocautery (Codman & Shurtleff, Inc., Raynham, Massachusetts, USA) with needle tip was used for dissections under endoscopic 0-degree view (Karl Storz GmbH & Co. KG, Tuttlingen, Germany). The electrical plate for the electrocautery was placed in the anterior part of the neck of the specimens with a small piece of metal in between the skin and the plate to complete the electric circuit.

Standard Nasoseptal Flap

Under visualization with a 0-degree endoscope, the middle turbinate was resected and the sphenoid ostium was identified as the superior limit of the nasoseptal flap pedicle. Four incisions were performed to dissect the standard nasoseptal flap: superior, inferior, anterior, and posterior. The superior incision was made immediately below the sphenoid ostium parallel to the skull base approximately 1-cm inferior to the nasal vault (olfactory sulcus). At the level of the attachment of the middle turbinate, the incision was turned superiorly toward the nasal dorsum. The cut then progressed anteriorly along the nasal dorsum to the caudal edge of the septum. The posterior incision started at the superior margin of the choana and extended along the posterior margin of the vomer toward the nasal floor up to the junction between the nasal floor and the septum. The inferior incision started at this point posteriorly running in the junction between the septum and the nasal floor and ended with joining the anterior

incision. The nasoseptal flap was elevated from the septum in the subperichondrial and subperiosteal plane to the anterior face of the sphenoid sinus and remained pedicled on the posterior septal artery.

Extended Nasoseptal Flap

Superior and anterior incisions were performed in the same way as described for the standard flap. To allow more room to dissect the mucosa of the inferior meatus, an oblique cut in the inferior turbinate axilla was performed and the turbinate elevated. The septum acted as a buttress to hold the inferior turbinate when moved superiorly. This maneuver guaranteed an excellent corridor to the inferior meatus improving the instrumentation and visualization for an effective dissection of the mucosa of the lateral wall. As opposed to the standard flap, the anterior incision was prolonged from the septum to the most anterosuperior part of the inferior meatus. The posterior incision was prolonged from the septum across the junction of the soft and hard palate to the most posterosuperior aspect of the inferior meatus. The equivalent of the inferior incision in the septum of the standard flap was a lateral incision, performed from the posterosuperior part of the inferior meatus to the anterosuperior part of the inferior meatus until it joined the anterior incision. The extended nasoseptal flap was elevated from the septum, nasal floor, and lateral wall of the inferior meatus in the subperichondrial and subperiosteal plane. The arterial branches that supply the septum and pass through the incisive foramen were sharply transected (► **Figs. 1 and 2**).

Panclival Approach

After both flaps were harvested, a complete sphenothmoidectomy and wide maxillary antrostomy were performed bilaterally. Each flap was carefully placed inside the ipsilateral maxillary sinus. The posterior portion of the septum was resected to allow room for binostril dissection. The septations inside the sphenoid sinus were drilled carefully with diamond burs. The sella, parasellar carotid, and cavernous sinus were identified bilaterally. Drilling the sphenoid floor allowed for the dissection and resection of the basopharyngeal fascia. The posterior wall of the nasopharynx behind the Eustachian tubes was incised, and the mucosa and longus capitis muscle were resected to expose the bone of the inferior third of the clivus and anterior arch of C1. The clivus below the sella was drilled and the dura mater was exposed from the sella to the foramen magnum. The lateral limits of the dissection were the lacerum and paraclival segments of the internal carotid artery superiorly and the hypoglossal canals inferiorly. The hypoglossal canal was located behind the Eustachian tube at the level of its inferior aspect. After a good exposure of the entire dura of the clivus was achieved, the standard and extended nasoseptal flaps were placed in the defect and their coverage was measured. Two different positions for the superior edge of the flap were analyzed: infratubercular and infraselar. Qualitative coverage of the cavernous sinus, different segments of the internal carotid artery, and relationships with the hypoglossal canals and clivus were assessed for both flaps.

Fig. 1 Technique of the extended nasoseptal flap performed with electrocautery (endoscopic tip) in an anatomical specimen, left side. (A) View of the inferior and middle turbinates. (B) Middle turbinate. (C) The middle turbinate is resected to increase the space to perform the flap. (D) The sphenoid ostium is found medial to the superior turbinate. (E) The incision begins below the ostium directed medially to the septum. (F) The incision runs parallel to the cribriform plate preserving the olfactory mucosa superiorly up to the attachment of the middle turbinate anteriorly. (G) At the level of the middle turbinate attachment, the incision is directed upwards to the dorsum. (H) The incision performed anteriorly in the dorsum. (I) Most anterior part of the incision in the septal cartilage (yellow arrows). (J) Gentle elevation of the inferior turbinate. (K) The anterior part of the inferior turbinate attachment is cut to allow more freedom for its superior dislocation. (L) Superior dislocation of the inferior turbinate. The septum acts as a buttress that holds the turbinate, facilitating the posterior and lateral flap incisions. (M) Inferior meatus and nasal floor after dislocation of the inferior turbinate. (N) Posterior incision in the septum (yellow arrows) and in the septal floor between the hard and the soft palate (arrowheads). (O) Lateral incision in the axilla of the inferior turbinate in the inferior meatus (green arrows). (P, Q) Dissecting the mucosa of the flap laterally. (R) Raising the flap medially and inferiorly. (S) Dissecting the flap from the septum. (T) Image of the nasal floor with the flap dissected superiorly. (U) The flap completely dissected laterally. The posterior septal arteries can be visualized in the mucosa of the septum. (V) The flap stored in the nasopharynx. Inf. Meatus, inferior meatus; Inf. Turb, inferior turbinate, Mid. Turb. Attach., middle turbinate attachment; Mid. Turb, middle turbinate; Post Sept. A, posterior septal artery; Septal Cart., septal cartilage; Sphen. Ostium, sphenoid ostium; Sup. Turb, superior turbinate.

Fig. 1 (Continued)

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Fig. 1 (Continued)

Comparison of the Flaps

The nasoseptal flaps were incised vertically just lateral to the sphenoid ostium level and extracted for measurements. The pedicle was dissected from the periosteal side in all the flaps to assess the number and distance of the posterior septal arteries to the superior incision (► **Fig. 3**).

Photoshop software v. 20 (Adobe Systems, New York, New York, USA) was used for measurements after taking pictures perpendicular to the flaps that were completely extended over an even surface. The measurements common to the standard and extended flaps were the following: D, distance from the most superior to the most inferior point in the pedicle (superior and inferior pedicular points); I, distance in the vertical plane between both pedicular points; A, anteroposterior distance from the superior point of the pedicle to the anterior part of the flap; and B, distance from the inferior point of the pedicle to the anterior part of the flap, parallel to A. The measurements that were different in the extended versus standard flap were the following: C, anteroposterior distance in the floor of the standard flap or junction between the septal and meatal parts of the extended flap; G' anteroposterior distance in the

transition between the septal surface and the meatal surface of the extended flap; G, anteroposterior distance in the inferior part of the extended flap that corresponds to the lateral incision; E, height of the flap in the pedicular part (up to the inferior incision in the standard flap and to the lateral incision in the extended flap); J, height of the extended flap in the pedicular part up to the nasal floor; and F, height of the flap in the anterior part at the level of the middle turbinate anterior attachment (up to the inferior incision in the standard flap and to the lateral incision in the extended flap). A descriptive and analytic study comparing both flaps was performed afterwards with SPSS software version 19 (IBM, Armonk, New York, USA).

Radiological Study

A radiological study was conducted to compare the size of the potential clival defect with the size of both types of flaps in the anatomical specimens. Helicoidal 1-mm thickness CT scans with neuronavigation protocol were acquired on all specimens before the dissection was started. OsiriX program (Pixmeo, Geneva, Switzerland) was used for reconstruction and measurements.

Fig. 2 The extended nasoseptal flap. (A, B) Steps of the septal incisions: (1) Incision parallel to the skull base below the sphenoid ostium to preserve the olfactory mucosa. (2) Anterior cut through the dorsum of the nose that extends laterally to the inferior meatus. (3) The anterior attachment of the inferior turbinate can be cut to elevate it easily. The turbinate is held by the septum after its elevation, creating a tunnel. (4) Posterior septal cut that extends across the junction between the hard and soft palate to the lateral nasal wall. (5) Lateral incision below the inferior turbinate attachment that extends significantly the surface of the nasoseptal flap. The blue line in A represents the inferior incision at the junction of the septum and the nasal floor in the standard nasoseptal flap. (C) Detail of the inferior turbinate elevation. The cut at the inferior turbinate axilla (step 3) is optional but facilitates the dissection.

Fig. 3 Right extended nasoseptal flap and left standard nasoseptal flap of the same specimen. The nasal floor and inferior meatus add a significant surface for clival reconstruction although the width of the defect is more limited inferiorly. The measurements common to both flaps are D, distance from the superior to the inferior pedicular point (orange dots); I, distance in the vertical plane between both pedicular points; A, anteroposterior distance from the superior point of the pedicle to the anterior part of the flap; B, distance from the inferior point of the pedicle to the anterior part of the flap, parallel to A; C, anteroposterior distance in the floor of the standard flap and meatal part in the extended flap. The measurements that differ in the extended versus standard flap are G', anteroposterior distance in the transition between the septal surface and the meatal surface of the extended flap. G, anteroposterior distance in the inferior part of the extended flap that corresponds to the lateral incision; E, height of the flap in the pedicular part (up to the inferior incision in the standard flap and to the lateral incision in the extended flap); J, height of the extended flap in the pedicular part up to the nasal floor; F height of the flap in the anterior part at the level of the middle turbinate (up to the inferior incision in the standard flap and to the lateral incision in the extended flap). The green line with blue, red, yellow, and green dots represents the reference points for the radiological study (points 1 to 4).

Using the midsagittal plane, the first step in the radiological analysis was to measure the distance from the tuberculum to the foramen magnum, adapting to the contour of the sella and posterior cortical of the clivus (K), and from the sellar floor to the foramen magnum (L) (►Fig. 4A). Those measurements represented the length of the potential clival defect that needed to be covered, considering the craniocaudal dimension of the nasoseptal flap.

Because of the change in the flap orientation when used to cover from the tuberculum or when used from the infrasellar clivus, four reference points in the sagittal plane were created to assess the most accurate axial oblique cuts for the measurements.

From the midsagittal plane in the CT scan, the images were progressed laterally until identification of the sphenoid ostium in the side of the extended flap. Once the ostium was found, a reference point 1 was placed just inferior and lateral to it. The next reference point annotated in the CT scan was point 2, corresponding to the inferior limit of the nasoseptal flap pedicle at the arch of the choana. To identify the correct location of point 2 in the sagittal CT scan, the measurement of the pedicular distance (distance D) obtained from the anatomical dissection of each extended nasoseptal flap was used. Starting from point 1 (inferior border of the sphenoid ostium), a line was drawn following the slope of the anterior wall of the sphenoid sinus with the measurement of the pedicular distance (distance D) from the dissection. Point 2 was marked at the inferior limit of that line. Following the same line created by points 1 and 2, a similar method was used to annotate points 3 and 4. Point 3 was placed at a distance J from point 1, representing the distance between the inferior border of the sphenoid sinus ostium and the nasal septum-floor junction. The distance between points 4 and 1 was the distance E obtained from the dissection between the inferior border of the sphenoid ostium and the inferior limit of the extended flap (►Fig. 4B).

After all four reference points were annotated in the sagittal CT scan, the next step was identifying the most accurate axial cuts to be used for the measurements of the clival width. When the flap is positioned to cover the tuberculum or to cover the infrasellar clivus, the length of septum mucosa necessary to cover the defect in a specific reference point will change because of the different flap orientation. Hence, two different axial cuts were used to measure the clival width in each reference point. For the tuberculum position, the axial cut passing through reference point 1 and the tuberculum, and the parallel planes below this level passing through points 2 to 4, were used (►Fig. 4C). For the coverage of the infrasellar clivus, the axial cuts selected were the one passing through point 1 and the floor of the sella turcica, and the parallel planes below this level (►Fig. 4D). In both axial cuts, the perimeter to be covered was measured from point 1 to the same approximate point contralaterally, and also the perimeter from point 1 to cover the contralateral carotid artery and cavernous sinus. In an inferior plane parallel to the first one, measurements were taken at point 2 in the same way. The flap is free inferior to point 2 (inferior pedicular point) and can be moved posteriorly. The measure-

ments of the area to cover in points 3 and 4 were taken as the corresponding clival defect posteriorly following both, the perimeter of the dura mater, and a straight line between the lateral limits. The Eustachian tubes and medial aspect of the hypoglossal canals were considered as a lateral limit of the approach (►Fig. 4E–H). The distances between the medial aspect of the hypoglossal canals, lacerum segment of the internal carotid artery, and medial aspect of the jugular foramina were measured in the neutral axial planes.

Results

Anatomical Dissections

The Nasoseptal Flap Coverage Area in the Clivus in the Anatomical Specimens

The standard nasoseptal flap was placed posteriorly in a horizontal fashion, turning the flap toward the clivus. In all the specimens, when the superior aspect of the flap was positioned just below the tuberculum, the height of the flap allowed a minimum coverage of the sella and the clival recess (►Fig. 5). The cavernous sinus was covered bilaterally in all cases. When placed inferior to the sella, the flap could cover a variable surface downwards, not fully reaching the foramen magnum in any of the studied cases. The oblique placement of the standard flap with its anteroposterior length oriented downwards covered a variable area with difficulties in reaching the foramen magnum completely, as a great portion of the flap was folded posteriorly to reach the deeper clival region. The craniocaudal coverage of the defect with the flap in the oblique position was almost the same as with the flap in the more natural horizontal position. However, the oblique placement of the flap was very limited in covering the carotids and the cavernous sinus bilaterally (►Fig. 5).

Regarding the extended nasoseptal flap, when its superior portion was placed over the tuberculum, the clivus could be covered up to the foramen magnum in 66.6% (8 out of 12) of the cases. The width of the defect covered was at least both cavernous sinus bilaterally, equivalent to the standard flap. This flap added to the standard flap a reconstructive surface inferior to the sphenoid floor. This inferior surface covered laterally at least up to the medial aspect of both hypoglossal canals. When the nasoseptal flap was placed inferior to the sella, defects up to the foramen magnum could be covered in all cases except one (91.6%) covering well laterally both carotid lacerum segments and medial hypoglossal canals in all cases (►Fig. 6). When the highest point of the flap was the tuberculum, the weakest coverage point of both flaps was the superior aspect of the parasellar internal carotid artery ipsilateral to the flap (►Fig. 6D).

Comparison of the Standard Nasoseptal Flap and the Extended Nasoseptal Flap

The extended flap has two parts: septal and inferior meatal. The septal part is superior and comprises the septal mucosa, equivalent in size and shape to the standard nasoseptal flap. It has a posterior pedicular portion below the sphenoid ostium between the origin of the superior and

Fig. 4 Measurements in computed tomography (CT) scans. (A) Clival measurements in sagittal CT scans in anatomical specimens. K, measurement from tuberculum to foramen magnum adapted to the contour of the sella; L, distance from the inferior part of the sella to the foramen magnum. (B) Some measurements taken of the extended nasoseptal flap were translated to the CT scan of the same specimen. Point 1 represents a position immediately lateral and inferior to the sphenoid ostium, point 2 represents the inferior part of the pedicle, point 3 represents the junction of the septal and inferior meatal part of the flap, point 4 represents the inferior part of the flap. Point 2 is located at D distance from point 1, point 3 is located at distance J from point 1 and point 4 at distance E from point 1. (C and D) The measurements were taken considering two different positions of the flap to cover clival defects in reconstruction: tuberculum (C) and infrasellar (D). The blue line represents the oblique axial plane used for the measurements in the tuberculum and infrasellar position for point 1, and the parallel planes below this one for points 2 (red line), 3 (yellow line), and 4 (green line). The measurements in the CT in the axial plane are infraestimated for the infrasellar position, as the flap has more room to be tilted and adapted (orange arrow and blue dots). (E–H) Measurements in the tuberculum position; all of them have been repeated for the infrasellar position. (E), Measurement in point 1 (superior part of the flap), in the plane shown with the blue line in C up to the same level contralaterally. The flap would ideally need to cover at least both carotid arteries, cavernous sinus, and tuberculum. (F) Plane parallel to E (red dotted line in C), measurement from point 2 covering the same areas as in E. (G, H) These CT planes (yellow and green dotted lines) are parallel to previous ones. The flap in points 3 and 4 is free from the pedicle and only the osseous structure to cover has been considered in a curved and linear fashion, not the distance from the point to the target. The clival resection has been considered restricted laterally by the Eustachian tubes when visible (blue dashed lines in G) or medial hypoglossal canals in H (blue arrows). Sphen. Ostium, sphenoid ostium.

Fig. 5 The standard and extended nasoseptal flap dissected in an anatomical specimen cut in the sagittal plane. (A) Standard nasoseptal flap on the left side, the superior incision is performed below the sphenoid ostium, preserving the olfactory mucosa superiorly, the inferior incision is placed in the junction between the floor and the septum. (B) Extended nasoseptal flap on the right side, showing the septal part (perichondrial-periosteal surface). (C) Standard nasoseptal flap reflected laterally. In the reconstruction, the flap will be placed in the opposite direction with the perichondrial-periosteal surface facing the defect. (D) The extended nasoseptal flap completely dissected. This flap has two parts: the septal part, which is superior and common to the standard flap, and an inferior portion; the inferior meatal part includes the mucosa over the nasal floor and inferior meatus. (E) The standard flap can be placed over the clivus in an oblique inferior fashion. The pedicle has to be folded downward, which reduces the effective surface for reconstruction. This flap limits both the width of the clival defect and the craniocaudal extension that can be covered. (F) Extended flap dissection that shows both parts of the flap. (G) The standard flap has been placed in a horizontal fashion. Although it does not cover in the studied cases a panclival approach defect, it would be suitable for smaller defects craniocaudally but would cover wider defects in the axial plane, such as contralateral cavernous sinus or even middle fossa in certain cases. (H) Placement of the extended nasoseptal flap toward the clivus. In this specimen it would cover the defect down to the foramen magnum. This flap gives valuable additional surface for reconstruction inferiorly. Ext. Nasoseptal Flap, extended nasoseptal flap; Front. A., frontopolar artery; Inf. Meatal Part, inferior meatal part; Inf. Turb., inferior turbinate; Mid. Turb., middle turbinate; Nasoseptal Flap Perichon.-Periost., nasoseptal flap perichondrial. periosteal. surface; Orb. A., orbitofrontal artery; Olf. Mucosa, olfactory mucosa; Sphen. Ostium, sphenoid ostium.

Fig. 6 Pictures showing the coverage area of the extended nasoseptal flap. (A-D). View with the 0-degree endoscope. (A) The clivus has been drilled and the clival dura mater exposed below the sella with the anterior arch of C1 partially exposed as a reference. The inferior limit of the foramen magnum and medial limit of the hypoglossal canals are represented with the green dashed lines. The extended flap on the left side is folded superiorly, showing its perichondrial surface. (B) The extended flap is being positioned over the clivus. (C) Extended flap placed over the clivus below the sella. Both parts of the flap, septal and meatal, can be recognized with orange and green dashed lines. (D) In this specimen the flap covers the surface from the tuberculum to the foramen magnum and its septal part laterally covers completely both parasellar carotid segments and cavernous sinus. When placed over the tuberculum recess, the weakest coverage point is the superior aspect of the ipsilateral carotid artery that requires more attention when placing the flap. (E) Anatomical specimen cut in the coronal plane. The clivus has been drilled and the dura mater resected. The border of the foramen magnum and anterior arch of C1 have been kept intact, as have the hypoglossal canals. The Eustachian tubes are displaced to the side. (F) The extended nasoseptal flap covers the sellar region and clivus up to the foramen magnum in 66% of cases. It covers the hypoglossal canals but does not reach the jugular foramina laterally. Car. A., carotid artery; Cerv. Seg., cervical segment of the internal carotid artery; CN, cranial nerves; ET, Eustachian tube; Ext. nasoseptal flap, extended nasoseptal flap; Hypogl., hypoglossal; For. Mag., foramen magnum; Inf. Meatal Part, inferior meatal part; Med. Hypogl. Canal, medial hypoglossal canal; Pit. Gland, pituitary gland; Seg., segment; Tuberc. Recess, tuberculum recess; Vidian N., vidian nerve.

posterior incisions, as well as an anterior reconstructive portion. The inferior meatal portion, only present in the extended flap, is formed by the mucosa of the floor of the nasal cavity and the mucosa of the lateral wall of the inferior meatus (►Fig. 3).

In both flaps, the posterior septal arteries irrigate the septal mucosa through the pedicular portion. The posterior septal arteries are branches of the sphenopalatine artery and enter the nasal cavity through the sphenopalatine foramen. At the level of the sphenoid ostium, the posterior septal arteries can run as a single branch that divides anteriorly (43.5% of cases) or as a double branch (56.5% of cases). If there is a single branch, the artery is located 7.02 mm below the sphenoid ostium (range 3.02 to 11.42 mm). If there is a double branch, the superior artery is located higher, 4.43 mm below the ostium (range 1.88 to 8.87 mm), and the inferior artery, with a bigger caliber, is located 9.45 mm below the ostium (range 4.63 to 13.92 mm) (►Fig. 7).

The Septal Part of the Extended Nasoseptal Flap and the Standard Nasoseptal Flap

To better analyze the flap, the pedicle was divided immediately inferior and lateral to the sphenoid ostium (►Fig. 3). Two points were considered in the pedicle; the superior pedicular point as the most superior and posterior point in the pedicle immediately lateral and inferior to the sphenoid ostium, and the inferior pedicular point as the most inferolateral point in the pedicle, superior to the choana. The

distance between these two points (D) is 14.25 mm (range 7.49 to 22.50 mm) and the distance in relation to the vertical plane (I) is 10.16 mm (range 6.50 to 18.86 mm).

The anteroposterior measurements were A = 57.75 mm (range 49.29 to 71.65 mm) at the superior pedicular point; B = 66.69 mm (range 58.47 to 73.62 mm) at the inferior pedicular point; and C = 59.45 mm (range 43.74 to 69.73 mm). The maximum anteroposterior measurement usually corresponds to the area inferior to B and superior to C. The posterior craniocaudal measurement of the standard flap (E) and the extended flap in the septal part (J) were similar. The anterior craniocaudal measurement in the standard flap in the most anterior part of the olfactory mucosa (F) is 31.96 mm (range 21.76 to 40.19 mm), being larger than the posterior measurement (E) (►Table 1).

All the common measurements performed in the septal part of the extended flap and standard flap showed no statistically significant differences between them in the U-Mann Whitney nonparametric test.

The Inferior Meatal Part and Proper Measurements of the Extended Flap

The inferior meatal part adds an inferior and posterior reconstructive surface to the standard flap. If we draw an anteroposterior line at the base of the septal part, the inferior meatal portion comprises an inferior addition in the posterior two thirds of this line approximately. The anterior third of the septal part comprises the septal mucosa equivalent to the

Fig. 7 Nose dissection. (A) Sagittal nasal dissection on the left side at the level of the middle turbinate. (B) View of the nasal septum. (C) Nasal septum after mucosal resection that shows its structure: the perpendicular plate of the ethmoid superiorly, vomer inferiorly, and quadrangular cartilage anteriorly. (D) Septal mucosa of the right-side periosteal-perichondrial surface. The posterior septal arteries—branches of the sphenopalatine artery—provide vascularization to the extended and standard nasoseptal flap. Ethmoid Perp. Plate, perpendicular plate of the ethmoid bone; Mid. Turb., middle turbinate; Odont., odontoid; Post. Septal Aa., posterior septal arteries; Quad. Cart., quadrangular cartilage; Sphen. Sinus, sphenoid sinus.

Table 1 Measurements related to the standard and extended nasoseptal flap based on ►Fig. 3

Variable (mm)	n	Minimum	Maximum	Average
A both	24	49.29	71.65	57.7504
B both	24	58.47	73.62	66.6967
C both	24	43.79	69.73	59.4513
D both	25	7.49	22.50	14.2520
I both	25	6.50	18.86	10.1692
E standard	12	25.70	34.85	29.5500
E extended	13	32.50	60.33	47.8692
J extended	13	17.43	34.75	27.7369
F standard	12	21.76	40.19	31.9600
F extended	13	43.09	65.72	55.6415
G' extended	13	30.39	45.42	37.0623
G extended	13	28.33	45.38	34.1469
Area standard	11	1,599.56	2,402.20	2,009.6545
Area extended	13	2,149.15	3,529.90	2,783.7015

external nose. After reaching the most anterior part of the septal mucosa, the anterior incision follows a significant step backward to meet the nasal floor and the inferior meatus. In contrast, the posterior incision is performed following the vomer posteriorly, continuing through the junction of the horizontal plate of the palatine bone with the soft palate in the nasal floor. This junction is approximately at the same level or a little posterior to the tail of the articulation between the inferior concha and the palatine bone. That makes the posterior incision continue smoothly from the junction of the hard and soft palate toward the posterior aspect of the inferior meatus. The flap slightly narrows at the upper part of the inferior meatus (►Figs. 2 and 3).

The anteroposterior distance at the upper limit of the inferior meatal part (G') is 37.06 mm (range 30.39 to 45.42 mm), whereas at the inferior limit (G) it is 34.14 mm (range 28.33 to 45.38). As described in ►Fig. 3, there is mucosa inferior to line G that has not been considered for reconstruction as it narrows downward, to be as restrictive as possible. Therefore, the differences in the Wilcoxon paired nonparametric test between G and G' are not significant.

As with the standard flap, the extended flap is significantly larger anteriorly at the anteroinferior level of the olfactory mucosa (F), which laterally corresponds to the level of the middle turbinate attachment, than posteriorly (E) $p = 0.002$.

When compared with the standard flap, the extended flap adds significant craniocaudal length to the flap. Posteriorly, the measurements of E in the extended flap are 47.86 mm on average versus 29.55 mm in the standard flap; anteriorly $F = 55.64$ mm versus 31.96 mm, both tests resulting in significant differences $p = 0.000$. The difference is approximately 21 mm of craniocaudal addition of mucosa for reconstruction. Compared with the standard flap, the area that the extended flap covers is significantly larger, 2,009.65 mm² versus 2,783.7 mm², $p = 0.000$. For all the measurements, there were no differences if the flap was performed in the right or left side.

CT Scans and Anatomical Measurements

The measurements in the CT scans of the same specimens dissected have two objectives: to measure more accurately the dimensions of the defect and coverage area, and to help to find a predictive model for assessment of the reconstructive area preoperatively. For the first objective, CT measurements of the potential defects were compared with the dimensions of the flap removed from the same specimen. For the second objective, the dimensions of the flap obtained with the dissections were compared with the dimensions of the flap obtained with the CT study of the same specimen. All these findings were verified with the results in the anatomical dissections exposed in the first part of the results taken as the gold standard.

The Clival Defect Sagittally

In the CT scans of the anatomical specimens, the distance from the tuberculum to the foramen magnum (K) was 51.98 mm (range 43.23 to 59.98 mm) and the infrasellar to the foramen magnum (L) was 36.29 mm (range 28.94 to 41.88 mm) (►Fig. 4).

When covering downward from the tuberculum, considering the measurement K and the most restrictive craniocaudal length of the flap that is E, the extended flap does not have enough length to cover that defect in all cases, being represented by the average of their differences in negative numbers as -3.98 mm (range -24.50 to 7.50 mm). Regarding the CT measurements, 7 out of 12 flaps were long enough to cover the defect. In the anatomical dissections, 8 out of 12 flaps covered the defect. In one case, there was enough length to cover the defect up to the foramen magnum in the dissection, but the CT analysis showed that the flap was lacking 3 mm inferiorly. Taken together, the distance E has a positive predictive value for craniocaudal coverage in the CT scans of 100%, but there is one false negative so the negative predictive value is 80%.

However, when covering the clivus below the sella, the difference between distance E and L is a positive 9.8 mm, (range -11.50 to 19.07 mm). In this case, all flaps except one covered the defect to reach the foramen magnum and the dissections showed the same results, so the positive and negative predictive values of the measurement E were 100%. Any good approximation of E preoperatively would be useful, as the positive and negative predictive values are high for both positions of the flap.

The Clival Defect Axially

Placing the flap superiorly at the tuberculum, the perimeter covering the entire surface from the superior pedicular point to the other side was measured in the CT scans (→Fig. 4). This coverage is common to the standard and extended flaps and depends on the distance A from the superior pedicular point, which corresponds to point 1 to the most anterior part of the flap in the nasal dorsum (→Figs. 3 and 6). The difference between A and this perimeter demonstrates that the flap covers the sella completely, both carotids, and both cavernous sinuses extending to the anterior contralateral wall of the sphenoid sinus in 50% of cases. The difference is -3.58 mm (range -20.08 to 8.89 mm). However, the flap was able to cover from the superior pedicular point to the contralateral cavernous sinus being the difference 6.15 mm (range 1.50 to 9.70 mm). This finding is consistent with the dissection that shows that all the flaps covered the bilateral parasellar carotid segments and cavernous sinus. Hence, the positive predictive value of measurement A regarding coverage up to the contralateral cavernous sinus is 100%.

When the flap is placed inferior to the sella, the distance to cover axially is greater to cover the clivus symmetrically beyond the contralateral carotid artery to the anterior sphenoidal recess. According to CT measurements, the flap would need 10 more mm on average to fully cover that area and would cover the clivus and the contralateral carotid artery in 63% cases. However, the dissections showed a wide coverage of this area by tilting the flap slightly superiorly; in 100% of cases, the flap covered both carotids at the paraclival and lacerum segments. The extended nasoseptal flap has its maximum anteroposterior length below both horizontal pedicular lines (lines A and B). When the flap is placed below the sella, the CT scan only predicts the actual coverage in 63% of cases, so the positive predictive value is 100% but the negative predictive value drops to 0. This means that an estimation of A is not a good estimate in reflecting the accuracy of the coverage in case the flap is placed below the sella and the CT shows a negative result.

Doing the same calculations for the inferior pedicular point (point 2 in the CT scan) and distance B, the flap covers the defect up to the same contralateral point when placed at the tuberculum. The difference between distance B and the perimeter calculated in the CT scan average greater than 10 mm (→Fig. 4). However, when it is placed in the infrasellar position, the flap will not be large enough to cover the defect up to the contralateral anterior recess, but it will be sufficient

for all the studied clival defects beyond the contralateral carotid artery. These findings are the same for dissections and CT scan measurements.

All the previous measurements were common to the extended and standard nasoseptal flaps as opposed to the measurements that include the inferior meatal surface. This added surface of the extended flap is located between points 3 and 4 in the CT scan. Point 3 corresponds to the transition between the septal and meatal part and point 4 corresponds to the lowest considered aspect of the septal part. Their anteroposterior corresponding measurements in the dissected flaps are G' superiorly and G inferiorly. The Eustachian tubes and the medial aspect of the hypoglossal canals are the lateral landmarks considered in this study. The dural perimeter and linear width between these lateral margins in the posterior limit of the clivus lining with the dura mater have been measured in points 3 and 4. Placing the flap in the tuberculum and below the sella, the flap had enough width to cover the clivus below the sphenoid floor in all cases except one in which point 3 was encountered at the clival recess, as it was a smaller flap. The coincidence between the measurements in the CT scans and dissections was complete.

Measurements of the Clival Width in the CT Scan

Some measurements of the clivus in the axial plane were taken to compare with distances G' and G to assess the sufficiency of the flap. The distance between the internal parts of both carotids in the foramen lacerum was measured (20.64 mm on average). The distance between the internal parts of both foramen jugulare was 40.72 mm and the distance between the internal parts of the hypoglossal canal was 27.58 mm. The septal part is almost always located below the sphenoid sinus floor and, according to our measurements, the flap would be enough to cover the distance between both lacerum segments (difference 16.22 mm on average) and hypoglossal canals (difference 6.94 mm), but not the foramen jugulare (difference -6.09 mm).

Predictive Model in CT Scans in Deciding to Raise an Extended Nasoseptal Flap

When considering a predictive model to decide whether a reconstructive flap has to be chosen, the most accurate but restrictive model needs to be designed. The accepted models were those that had no significant differences between the predicted and the real measurements, or ones in which the differences were inferior in the predictive model but not relevant, considering these differences to be less than 5 mm.

Several easy steps are considered for taking the predictive measurements in the CT scan, (→Fig. 8):

Sagittal Plane

1. Find the sphenoid ostium in the sagittal plane, then in the plane of the septum measure the distance from a line just below the ostium and extend it horizontally to the dorsum, which is equivalent to measurement A of the flap. When performed in CT scans and measured with real flaps, there

Fig. 8 Predictive model to estimate the flap coverage with a preoperative computed tomography (CT) scan. After the measurements explained in these pictures are estimated, the process is the same as described in ► **Figure 4**. (A) Predictive A is calculated in the septum from a point inferior to the sphenoid ostium (seen in a more lateral CT plane) to the dorsum of the nose. (B) Predictive G' is obtained lateral to the septum measuring the hard palate. (C) Predictive G is measured as an anteroposterior distance below the inferior turbinate attachment (orange dashed line). (D) Predictive J is taken in the coronal plane, inferior to the sphenoid ostium (seen in a more posterior coronal plane) to the septum-floor junction and extended to the posteriosuperior aspect of the inferior meatus to obtain E. These two measurements are taken in a coronal plane located at the level of the junction between the soft and hard palate.

- were no significant differences according to Wilcoxon nonparametric paired test.
2. Measure the distance from the anterior to the posterior part of the hard palate, which is equivalent to the distance G'. The comparison of these measurements in our flaps and the corresponding CT scans showed no significant differences in the nonparametric paired test.
 3. Just lateral to the inferior turbinate attachment, measure the osseous attachment that would be an estimate of the distance G. The paired test showed that the estimated length was inferior to the measured length in the actual flap $p = 0.016$, but the averages were 30.29 mm for the predicted length versus 34.14 mm of the actual length. The difference was considered to not be clinically relevant and an advantage of the model, as the predicted length was inferior to the real.

Coronal Plane

1. Localize the sphenoid ostium, advance anteriorly to the junction of the hard and soft palate. Measure the distance from a line immediately inferior to the ostium up to the junction of the septum and the floor of the nasal cavity; this is equivalent to distance J.
2. Measure the distance from the same point superiorly to the attachment of the inferior turbinate inferiorly; this is distance E. The differences were inferior in the predicted model, less than 5 mm on average.

Application of the Model

1. Place three points in the model to make it simpler: points 1, 3, and 4 as described in Methods (► **Fig. 4**).
2. Place point 1 just below the sphenoid ostium.
3. Place point 3 at distance J and point 4 at distance E from point 1, following the anterior slope of the sphenoid sinus.
4. Locate the center of the axis in the sagittal plane in point 1. Considering the defect predicted in surgery, move the vertical plane backward up to the point where the flap will cover superiorly.
5. In the axial plane placed in point 1, check the perimeter to cover and compare with predicted value A in the sagittal CT scan.
6. Move the axial plane downward up to point 3 parallel to the plane described for point 1. Compare the perimeter to cover with predicted G', this is the junction between the septal and meatal part, so from this point downward the flap is smaller in size.

7. In the plane placed in point 4, compare the desired coverage area with the predicted value G.

This list outlines a restrictive model for considering the extended flap to be used in clival defects with a high predictive positive value. The same model can be applied to the standard nasoseptal flap measuring the distance at the base of the septum.

Discussion

Since the publication of nasoseptal flap articles for skull base reconstruction, numerous studies have analyzed these and other vascularized flaps based on dissections in anatomical specimens and radiologic measurements or both.^{1,2,4–15} Clinical series have been published focusing on indications and outcomes, and all agree in the dramatic reduction in the incidence rate of postoperative CSF leak.^{2,16}

The dissections in this study were performed with electrocautery, as used in surgery, to minimize an overestimation of flap measurements due to mucosal shrinkage. Radiologic studies have considered the possibility of estimating the reduction in flap size as up to 6 mm.⁴

While performing these anatomical dissections, several technical details were found to be useful:

- Although optional, incising the anterior head of the inferior turbinate and dislocating it upwards makes the dissection easier. The septum acts as a buttress, holding the turbinate and giving view and more freedom to incise and dissect the mucosa. This maneuver also improves the angle for the incision between the nasal floor and the caudal border of the septum.
- A place where there is a risk of tearing the flap was encountered below the junction of the nasal spine of the maxilla and the quadrangular cartilage anteriorly. The mucosa over the maxilla is significantly thinner and, in some cases, there is a lateral prominence formed by the union of both structures.
- Another point where care should be taken is located at the level of the anterior incisive foramen, because nerves and arteries are passing through; sharp dissection is advised at this point.
- In the lateral wall of the inferior meatus, because the bone is very thin and in some parts incomplete, unintended opening of the maxillary sinus can occur.
- Care must be taken with the incision between the soft and hard palates to avoid lesioning the muscles of the soft palate. The junction between hard and soft palates is approximately at the same level or slightly posterior to the tail of the articulation between the inferior concha and the palatine bone.
- As with the standard flap, the most attached mucosa is found anteriorly, close to the nostril and thus constitutes another area of easy tear.

The nasoseptal flap for anterior cranial base reconstruction has been demonstrated to completely cover craniofacial

resections in an anatomoradiological study.³ The nasoseptal flap is pedicled in the posterior aspect of its superior half, and the inferior half has more freedom to be manipulated. The orientation of the nasoseptal flap for anterior skull base reconstruction implies a superior rotation, whereas for clival defects it is placed posteriorly, rotating the flap as a book with less superior or inferior displacement. In both cases, the pedicle needs to be free from tension to preserve arterial blood flow. An oblique inferior placement of the standard flap in the clivus is also possible, resulting in a reduction of the reconstructive surface superiorly to place both edges in the clivus deep and equidistant from midline. The width of the defect that could be covered would be represented by the distances E and F of the standard flap in this case, whereas the minimum width covered by the extended flap would correspond to distances G and G' (meatal part), both significantly larger than E and F $p = 0.012$ and $p = 0.001$, respectively. Moreover, the extended flap offers a wide area superiorly to cover the defect beyond both carotids. Some large tumors involve clivus and Meckel cave dissections, and this flap can be an option for reconstructing the skull base laterally and inferiorly. If the anteroposterior length of the septal part of the extended flap is not large enough to reach the contralateral part due to the clival depth or angle, a fat graft can be placed in the defect, making the surface to reconstruct smaller as the depth would be significantly reduced.

The extended nasoseptal flap increases the reconstructive area significantly by 774 mm², as well as the craniocaudal length to be covered by 21 mm. This implies that the defects can be covered up to the foramen magnum in 91.66% cases of cases if placed below the sella and in 66.6% of cases if placed superiorly at the tuberculum.

One of the limitations of the flap, besides the craniocaudal length, is the anteroposterior length of the meatal part that leaves the anterior third of the septum without inferior mucosal addition.

Distances between both the foramen lacerum and medial aspect of the hypoglossal canals were largely covered by the meatal part, whereas widths of the clival defect that go laterally up to the medial part of the jugular foramina were too large for this flap. For these defects, other reconstructive flaps have to be considered, such as a large pericranial flap.^{14,15}

Based on this work, a predictive model has been described to assess preoperatively the convenience of raising an extended nasoseptal flap. It has been designed to be restrictive, as some of the measurements were inferior to the real raised flap but limited to less than 5 mm. The reason for that can be explained by the technique of measuring that does not take into account the little curves of the mucosa, considered and measured as a single line. The measurements and estimations are accurate in predicting preoperatively the craniocaudal coverage length. A CT estimation of coverage considering measurement A of the flap has been demonstrated to be more useful when the flap is placed below the tuberculum than when it is placed below the sella. Although the estimations of the CT scans are less reliable in the last case, dissections show that the length is enough to cover both carotids at least.

Close estimations of the measurements of the inferior meatal part have shown to be very accurate in predicting the coverage area below the tuberculum and below the sella. The advantages of a restrictive model are that different reconstructive techniques can be planned ahead of time and used if needed. In an unclear case, the suggestion would be to raise the extended flap and, if is not enough, be ready for other options.

Conclusion

The extended nasoseptal flap adds the mucosa of the nasal floor and inferior meatus to the standard nasoseptal flap. Its indications are mainly reconstruction of the clival defects in endoscopic skull base surgeries. The flap is large enough to cover longitudinally the clivus for infrasellar defects up to the foramen magnum in most cases and covers from the tuberculum inferior completely in two thirds of cases. The width of the mucosa constituting the meatal part of the flap limits its reconstructive area to the lateral limits of Eustachian tubes and hypoglossal canals. A restrictive predictive model for preoperative planning has been described.

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