

## ORIGINAL RESEARCH

## Radioanatomical study of the extended free nasal floor mucosal graft and its clinical applications

Jaime González-García MD<sup>1</sup> | Ramón Moreno-Luna MD, PhD<sup>1</sup>  |  
 José Palacios-García MD<sup>1</sup>  | Alfonso Del Cuvillo Bernal MD, PhD<sup>2</sup>  |  
 Juan M. Maza-Solano MD, PhD<sup>1</sup>  | Jaime Santos Pérez MD, PhD<sup>3</sup> |  
 Carlos D. Pinheiro-Neto MD, PhD<sup>4</sup> | Serafín Sánchez-Gómez MD, PhD<sup>1</sup>  |  
 Jesús Ambrosiani Fernández MD, PhD<sup>5</sup> 

<sup>1</sup>Rhinology Unit, Department of Otolaryngology, Hospital Universitario Virgen de la Macarena, Sevilla, Spain

<sup>2</sup>Rhinology and Asthma Unit, ENT Department, Hospital de Jerez, Jerez de la Frontera, Cádiz, Spain

<sup>3</sup>Rhinology Unit, Department of Otolaryngology, Hospital Clínico Universitario de Valladolid, Valladolid, Spain

<sup>4</sup>Division of Otolaryngology/Head and Neck Surgery, Department of Surgery, Albany Medical Center, Albany, New York, USA

<sup>5</sup>Department of Human Anatomy and Embryology, Faculty of Medicine, Universidad de Sevilla, Sevilla, Spain

## Correspondence

Ramón Moreno-Luna, MD, PhD, Rhinology Unit, Department of Otolaryngology, Hospital Universitario Virgen de la Macarena, Avda. Doctor Fedriani 3, E-41071 Sevilla, Spain.  
 Email: ramoluorl@gmail.com

## Abstract

**Objectives:** To perform a radio-anatomical evaluation of the nasal cavity floor free mucosal graft (endonasal extended mucoplasty, EEM) to repair mucosal defects after an extended ethmoid-sphenoidotomy.

**Methods:** A human cadaveric study (radiological and anatomical dissection) and an in vivo study in surgical patients with CRSwNP were performed. The EEM areas were compared between 3D reconstruction from CT scans and anatomical/surgical dissections, both in cadaver specimens and in patients. Feasibility was assessed by correlation between the EEM area on CT scans and when harvested in cadavers and when grafted in patients. Usefulness was assessed by the degree of coverage of the EEM in the surface exposed after an extended ethmoid-sphenoidotomy. Both feasibility and usefulness were assessed in cadaveric specimens (n = 15) and patients (n = 4).

**Results:** Fifteen cadaveric specimens and 4 patients with bilateral CRSwNP were included. The mean (SD) areas obtained in the cadaveric radiological and anatomical studies were 9.44 (2.07) cm<sup>2</sup> and 8.03 (1.36) cm<sup>2</sup>, respectively (intraclass correlation coefficient 0.59, moderate correlation), and in 3D reconstruction for operated patients were 10.32 (0.98) cm<sup>2</sup> and 11.27 (2.44) cm<sup>2</sup>, respectively. The coverage of the ethmoidal roof in the cadaveric dissection study was 100%, from the anterior ethmoidal artery to the posterior ethmoidal artery, covering the planum sphenoidale up to 75% in the case series. In 87.5% of the cases, up to 50% of the papiroca lamina was covered.

Jaime González-García and Ramón Moreno-Luna contributed equally as first authors.

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**Conclusion:** The EEM have shown to be a feasible and useful grafting technique to repair skull base defects after performing an extended ethmoid-sphenoidotomy during surgery for CRSwNP.

**Level of Evidence:** NA.

**KEYWORDS**

chronic rhinosinusitis with nasal polyps (CRSwNP), endonasal extended mucoplasty (EEM), grafting techniques, skullbase defects

## 1 | INTRODUCTION

The development of different grafting techniques has contributed significantly to the rhinological and skull base surgery. Various free grafts, both synthetic and autologous, have been used as effective repair materials for endoscopic closure of skull-based defects in low-grade fistulas,<sup>1</sup> during non-complicated transsellar surgery,<sup>2</sup> for the closure of septal perforations,<sup>3</sup> and as complementary treatments in chronic rhinosinusitis with nasal polyps (CRSwNP).<sup>4</sup> Free grafts used as a cover for the ethmoidal basicranial roof, after performing a complete ethmoid-sphenoidotomy, have shown to improve local healing with less edema.<sup>4</sup>

Free endonasal mucosal grafts have no vascular pedicle to preserve and, in contrast to other vascularized flaps, there are no spatial limitations at the time of placing the graft inside the nasal cavity. Donor mucosal sites for free endonasal grafts are diverse, including turbinate structures,<sup>5</sup> the nasal septum<sup>6</sup> or the endonasal floor,<sup>7</sup> being free middle turbinate grafts the most commonly used.<sup>5,6</sup>

Different radiological models have been used to improve the design and to correlate measures of nasoseptal flaps for skull base reconstruction.<sup>8</sup> The new radiological multiplanar and 3D reconstruction techniques for computed tomography (CT) scan allow for a more precise and detailed anatomical study of the nose, paranasal sinuses, and anatomical variants, and can be useful to determine the mucosal coverage area for repairing certain defects in skull base surgery or to accurately identify the region to be covered in the ethmoidal roof and orbital wall, when extended ethmoid-sphenoidotomies are planned.<sup>9,10</sup>

The objective of this study was to perform a radioanatomical study to assess the feasibility and usefulness of the mucosal free graft from nasal cavity floor (endonasal extended mucoplasty, EEM) to repair defects after performing an extended ethmoid-sphenoidotomy.

## 2 | METHODS

A human cadaver study, including a radiological and an anatomical dissection study, was designed to assess the feasibility of the EEM. The performance of the EEM was subsequently evaluated in a prospective case series of patients with bilateral CRSwNP.

Inclusion criteria for cadaveric specimens were caucasian adults, with no history of head and neck surgery or trauma. Gender and

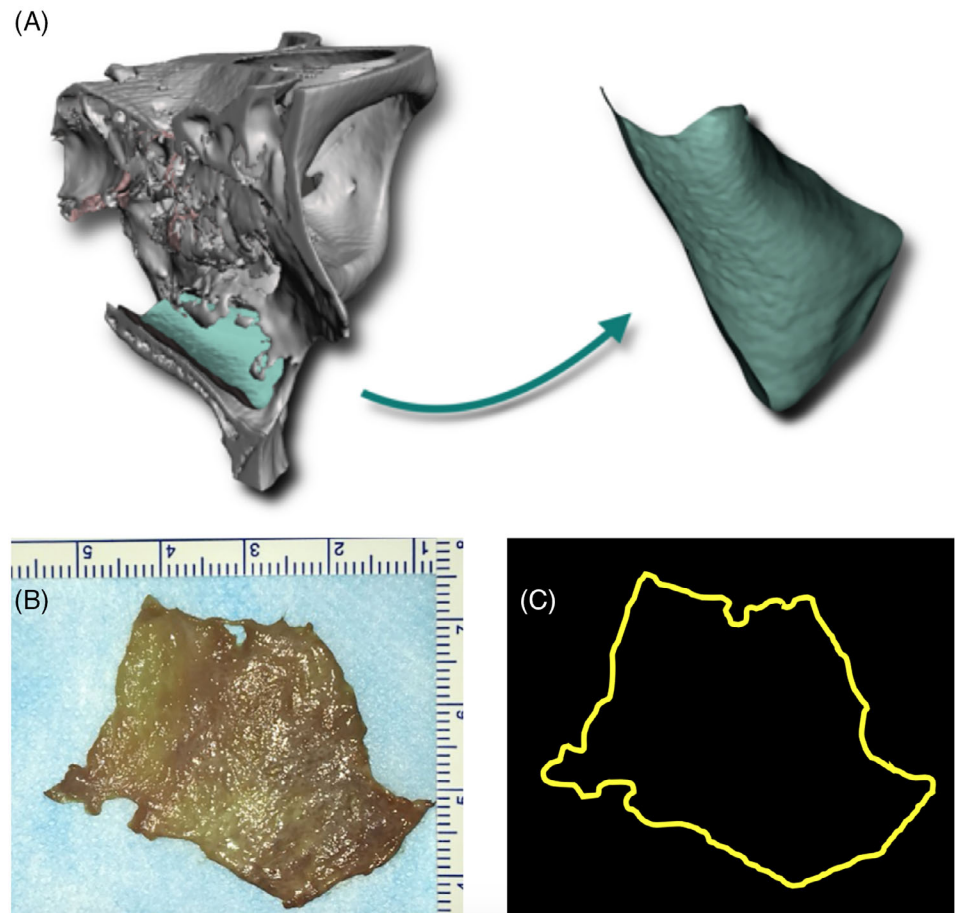
causes of death were unknown. Patients for the case series were selected from the Rhinology Unit of a tertiary care hospital in Sevilla, Spain. Eligible patients have to meet diagnostic criteria of CRSwNP established by the European Position Paper on Sinusitis (EPOS).<sup>11</sup> Inclusion criteria were: patients of both genders, aged 18 years or older, with a nasal polyp score for each nostril of 2 (moderate-sized polyps not crossing the lower edge of the inferior turbinate) or 3 (large polyps crossing the lower edge of the inferior turbinate) using the Lidholdt's scale.<sup>12</sup> Patients with CRS without or with unilateral nasal polyposis were excluded from the study, as were patients with systemic diseases, neoplasms, history of prolonged use/abuse of decongestant nasal spray (ie, xylometazoline) and pregnant or breastfeeding women. All participants met indication for surgical treatment as outlined by Rudmik et al.<sup>13</sup> Patients underwent an extended ethmoid-sphenoidectomy with bilateral grade III frontal sinusotomy for treatment of bilateral CRSwNP. Details of the surgical procedure have been previously reported.<sup>4</sup>

All participants were fully informed of their participation in the study, the surgical procedure to perform and they signed a written informed consent. The study was approved by the Ethics Committee for Clinical Research of the Hospital Virgen Macarena, Seville, Spain.

### 2.1 | Radiological study

CT scans were performed on cadaveric specimens and in patients undergoing extended ethmoid-sphenoidotomy and EEM. A sagittal 3D skull reconstruction was performed from the side selected for the harvesting of the EEM in the anatomical study, using a DICOM (Digital Imaging and Communication on Medicine) viewer (HOROS software). The Meshmixer software was used to draw the limits of the EEM from the 3D reconstruction of the nasal fossa analyzed, and to obtain a 3D image of the surface of the nasal floor graft that was saved in a STL file (Standard Triangle Language) (Figure 1A). The limits of the EEM drawn were as follows: anteriorly, the orifice pyriform; laterally, the attachment of the inferior turbinate; posteriorly, the posterior edge of the palatine bone; and medially, the upper edge of the vomer bone. The Meshlab software was used to obtain the measures of the 3D image of the surface of the nasal floor graft. In the case series study, the area of the harvest graft in the CT scan was measured using the same methodology than in the cadaveric study.

**FIGURE 1** A, CT 3D draw mucoplasty and 3D mucoplasty extracted; B, Cadaveric mucoplasty; C, Cadaveric mucoplasty drawing to measure. CT, computed tomography



## 2.2 | Anatomical study

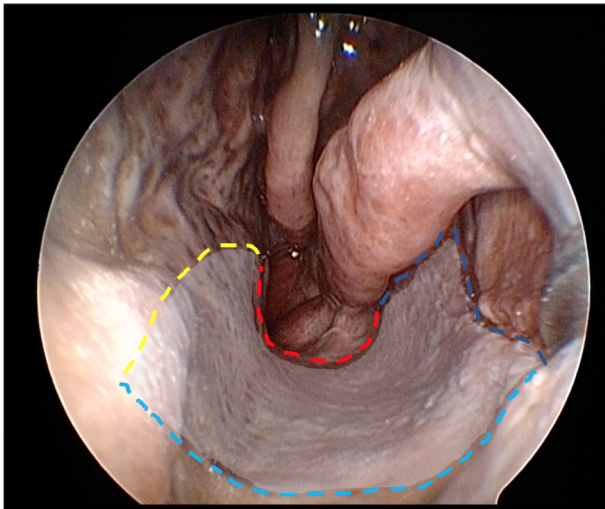
Cadaveric and in vivo studies using the same method were carried out to assess the measurement of the EEM and the usefulness of the EEM to cover the surface exposed after an extended ethmoid-sphenoidotomy. Endoscopic sinus dissections were performed in fresh preserved cadaveric anatomical specimens. All dissections were performed with a 0° ENT endoscope (HOPKINS II Wide-Angle Straight Forward Telescope 0°, Karl Storz Endoscopia Ibérica, S.A., San Fernando de Henares, Madrid, Spain), and no electrocautery was used.

In order to measure the EEM, the graft was initially harvested during anatomical dissection. The first step was the medial dislocation of the inferior turbinate. The posterior limit was the posterior border of the horizontal portion of the palatine bone, which has a smooth and concave edge. This limit can be identified by a previous palpation with the tip of the scalpel. The medial limit of the nasal graft was located on the upper edge of the vomer bone, preserving the cartilaginous portion of the septum and the perpendicular lamina of the ethmoid bone in the posterior third of the dissecting specimen. This dissection was performed on a bone plane. The lateral limit reached the attachment of the inferior turbinate along the lateral wall of the nasal fossa. The Hasner's valve was preserved. Anteriorly, the limit was a few millimeters behind the skin of the nasal vestibule, in the pyriform orifice. Figure 2 shows the limits of the EEM in one of the

specimens. In order to calculate the areas of the EEM in  $\text{cm}^2$  a photograph of the extended graft was obtained after its removal from the nasal cavity. A ruler was placed next to the graft in the same photograph to determine how many pixels per square centimeter ( $\text{px}/\text{cm}^2$ ) were included. The image J was used to draw the area of the extended graft and to obtain the number of pixels and then the area in  $\text{cm}^2$  (Figure 1B,C).

To assess the usefulness of the EEM to cover the area exposed, after EEM extraction, the endoscopic cadaveric dissection was completed by a total endoscopic surgical elimination of the anterior and posterior ethmoid cells and a sphenoidotomy in addition to a bilateral grade III frontal sinusotomy. The anterior and posterior ethmoidal arteries were identified bilaterally. Subsequently, the mucosa at the anterior cranial base and lamina papyracea was completely removed, and the residual septations were drilled out leaving those areas flushed and ready to receive the free mucosal graft. The graft was placed to cover the anterior skull base always in the same way. The anterior limit of the EEM was the anterior ethmoidal artery, then, it was laid posteriorly along the ethmoidal roof towards the planum sphenoidale. The medial limit was the insertion of the inferior turbinate. Laterally, it was placed covering a large portion of the lamina papyracea.

The area of the graft after EEM during surgery was measured using the same methodology; both nostrils were evaluated. To assess the usefulness of the EEM to cover the area exposed after the



**FIGURE 2** The limits of the EEM. The medial limits: yellow dashed line; anterior limits: light blue dashed line; posterior limits: red dashed line; lateral limits: blue dashed line. EEM, endonasal extended mucoplasty

extended ethmoid-sphenoidotomy, two surgeons performing the dissection completed and agreed a previously defined and validated landmarks check-list.<sup>9</sup>

### 2.3 | Outcome measures

Outcome measures included feasibility and usefulness of the EEM graft. Feasibility was defined as the concordance between the area of the EEM measured in the CT scan and the area of the harvested EEM performed in cadaveric specimens and in clinical cases. Usefulness was defined as the coverage of the EEM after placement, which was assessed by the percentage of cases that reached the landmarks proposed, both in the cadaveric anatomical study and in the case series study.

### 2.4 | Statistical analysis

Categorical variables are expressed as frequencies and percentages, and continuous variables as mean and SD. The intraclass correlation coefficient (ICC) (ie, a measure of concordance between two or more continuous quantitative assessments obtained with different instruments or different researchers) was used to assess the concordance between the area of the EEM measured in the CT scan in the radiological cadaveric study and the area of the EEM graft drawn and harvested in the cadaveric anatomical study. ICC values less than 0.5 are indicative of poor correlation, between 0.5 and 0.75 indicate moderate correlation and greater than 0.90 indicate excellent correlation. R: A language and environment for statistical computing was used to the statistical analysis (R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>).

**TABLE 1** Feasibility of the EEM (surface measurements graft by CT and cadaveric dissection)

Cadaveric head	Coverage area, cm <sup>2</sup>		Nasal cavity
	CT EEM surface measurement	Dissection EEM surface measurement	
1	8.848	7.99	Right
2	9.416	8.14	Left
3	10.721	8.34	Left
4	11.473	10.31	Right
5	11.756	7.66	Right
6	7.330	6.8	Left
7	7.408	6.94	Left
8	8.313	7.83	Left
9	14.907	8.18	Right
10	7.290	6.23	Right
11	8.524	7.20	Right
12	9.379	9.39	Right
13	8.117	7.2	Left
14	9.818	11.2	Left
15	8.308	7	Left
Mean (SD)	9.44 (2.07)	8.03 (1.36)	

Abbreviations: CT, computed tomography; EEM, endonasal extended mucoplasty.

## 3 | RESULTS

A total of 15 cadaveric specimens and 4 patients with bilateral CRSwNP were included in the study.

### 3.1 | Cadaveric specimens

In relation to feasibility, details of CT radiological measurements of 3D reconstructed EEM graft and measurements of the EEM surface obtained in the cadaveric specimens are shown in Table 1. The minimum and maximum mucosal areas obtained in the radiological study were 7.29 cm<sup>2</sup> and 14.91 cm<sup>2</sup>, respectively, with a mean (SD) area of 9.44 (2.07) cm<sup>2</sup>. In the anatomical study, the minimum and maximum mucosal coverage areas obtained in the dissection from cadaveric specimens were 6.8 cm<sup>2</sup> and 11.2 cm<sup>2</sup>, respectively, with a mean (SD) area of 8.03 (1.36) cm<sup>2</sup>. Concordance between the cadaveric EEM CT radiological measurement and the measurement of the EEM obtained from cadaveric dissection was moderate (ICC = 0.59, moderate correlation).

In relation to usefulness, an extended ethmoid-sphenoidectomy and bilateral grade III frontal sinusotomy could be performed in 100% of cadaveric dissections. The landmark areas covered by EEM in cadaveric specimens study are shown in Table 2. Coverage of the ethmoidal roof was possible in 100% as well as coverage of both anterior and posterior ethmoidal arteries (100%). The papyracea lamina was covered in craniocaudal way by EEM at 75% of its length by 2 cases (13.3%), at 50% by 15 cases (100%), and totally covered at 100% in

**TABLE 2** Usefulness of the extended endonasal mucoplasty EEM in the cadaveric anatomical study and in the clinical series of patients with bilateral CRSwNP

Variables	Cadaveric study no. (%)	Patients (two nostrils) no. (%)
Placement of extended mucoplasty (coverage of the free graft after insertion)	15 (100)	8 (100)
Covers the anterior ethmoidal artery	15 (100)	8 (100)
Covers the anterior ethmoidal roof	15 (100)	8 (100)
Covers the posterior ethmoidal artery	15 (100)	8 (100)
Covers the planum sphenoidale	15 (100)	6 (75)
Covers the tuberculum sellae	8 (53.3)	4 (50)
Covers the lamina papyracea		
25% coverage	15 (100)	8(100)
50% coverage	15 (100)	7(87,5)
75% coverage	2(13,3)	2(25)
100% coverage	0(0)	0(0)
Reaches the maxillary-ethmoid angle	8(53,3)	4(50)

Abbreviation: EEM, endonasal extended mucoplasty.

**TABLE 3** Demographic and clinical data in 4 patients

Variable	Number patients (%)
Age, years, mean (SD)	47 (13.4)
Women	2 (50)
Asthma comorbidity	4 (100)
Reintervention	1 (25)
Lindholdt score, mean (SD)	2.75 (0.8)
Lund-Mackay score, mean (SD)	21.75 (2.63)

Note: Data as frequencies and percentages in parenthesis unless otherwise stated.

no case (0%). With respect to the planum sphenoidale, it was possible to reach 15 cases (100%), but this could not be achieved completely in 3 of those cases (20%). Thus, sphenoidal tuberculum was covered in 8 cases (53.3%) and could not be covered in 7 cases (46.7%) (Table 2).

### 3.2 | In vivo specimens

In all 4 patients with severe CRSwNP surgery was successfully performed with an extended ethmoid-sphenoidectomy and bilateral

grade III frontal sinusotomy (Table 3). The EEM was harvested in each nostril of patients. Intraoperative or postoperative complications after 1-month of follow-up were not recorded.

In relation to feasibility, individualized CT scan measures of the EEM area as well as the harvested graft surface area, with details of the covered site in the nostrils of each patient are described in Table 4. The media and SD of EEM surface in the CT scan 3D reconstruction from patients was 10.33 (0.98) and the media (SD) of the surgical harvested graft was 11.27 (2.44).

In relation to usefulness, the landmark areas covered by the EEM graft are shown in Table 2.

## 4 | DISCUSSION

Our radioanatomical cadaveric and in vivo study of the endonasal extended mucoplasty shows that this grafting technique is feasible and useful to repair defects after performing an extended ethmoid-sphenoidectomy and bilateral grade III frontal sinusotomy.

In the cadaveric study, we have used measurements taken by CT and 3D reconstruction techniques to assess the dimensions of EEM graft and have compared them with the EEM surface area obtained by cadaveric dissection to assess feasibility of the procedure. Pre-dissection radiological measurement of the mean dimensions of the graft was 9.44 (2.07) cm<sup>2</sup> and provided a reliable assessment of the usefulness of the EEM to ensure mucosal coverage area after an extended ethmoid-sphenoidectomy and prior to the extraction of the graft. The radiological measurements applied in our 3D radioanatomical study offers the possibility to extract measurements from irregular surfaces. In other studies, the radiological measurement was performed from axial, sagittal, and coronal images.<sup>8</sup> This radiological methodology could be applied to measure grafts or even pedicle flaps in other locations.

The mean surface area for the EEM (8.03 [1.36] cm<sup>2</sup>) in the cadaveric specimen is similar to that obtained with free middle turbinate grafts,<sup>14</sup> but smaller than the simple (12.3 [2.3] cm<sup>2</sup>) or extended (28.8 [3.3] cm<sup>2</sup>) nasal floor and inferior meatus flap, as reported by Santamaria-Gadea et al.<sup>15</sup> However, they have the limitation of the mucosal surface necessary for the rotation of the pediculated flap.

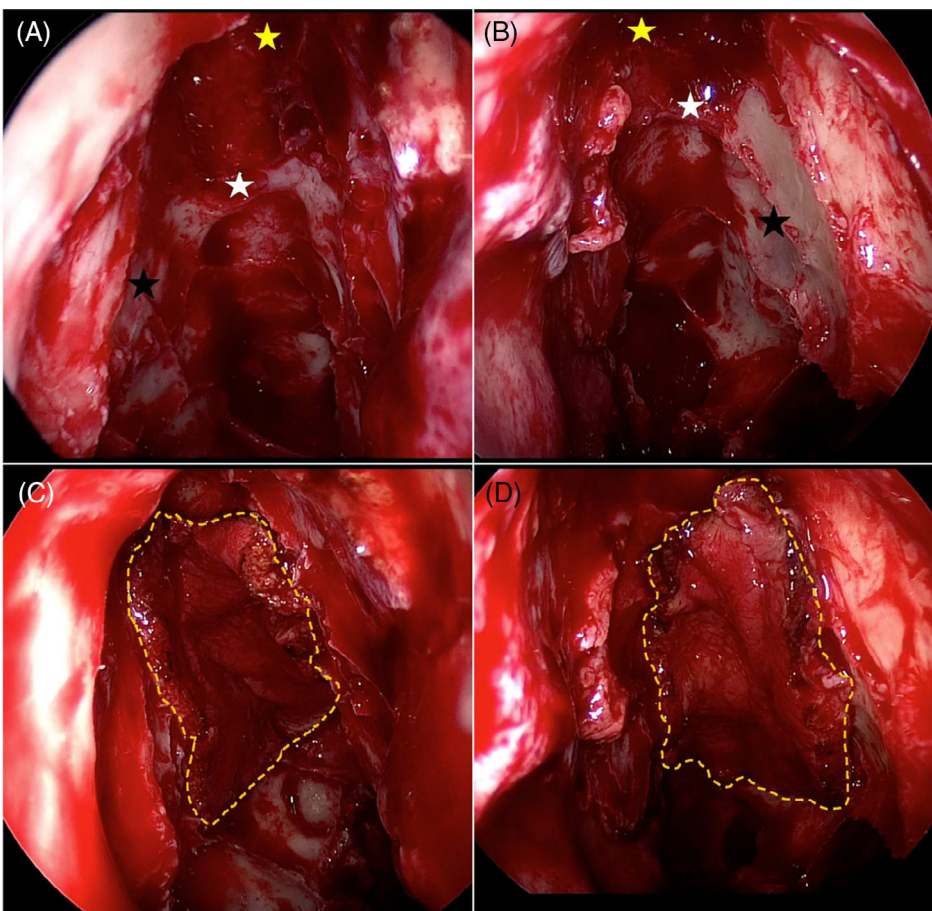
Our group has recently described the clinical feasibility and usefulness of free nasal floor mucosal grafting to cover the anterior skull base, from the anterior ethmoidal artery to the sphenoidal region and the upper third of the orbital wall, in patients operated by means of an extensive ethmoid-sphenoidotomy for CRSwNP.<sup>4</sup> Comparing the left grafted nostril with the right non grafted nasal cavity, that served as control, better postoperative healing was observed at 6 months, with a decrease in local edema.<sup>4</sup> At 1 year of follow-up, an improvement in quality of life was observed in this group, thus reinforcing the usefulness of this graft.<sup>16</sup> The EEM could offer the opportunity to cover a larger surface of the skull base for better local healing (Figure 3). In this regard, the study also included the potential coverage area for the ethmoid-sphenoidal roof and orbital wall, for use of the EEM in endonasal endoscopic sinus surgery (EESS). Dadgostar



**TABLE 4** Radiological and clinical study of EEM in 4 patients with bilateral CRSwNP undergoing an extended ethmoid-sphenoidotomy

Patients sex, age (years)	CT scan area measures, cm <sup>2</sup>		Harvested graft surface, cm <sup>2</sup>		Covered site	
	Right nostril	Left nostril	Right nostril	Left nostril	Right nostril	Left nostril
Female, 47	9,26	9,45	15.90	10.05	AEA, PEA, ethmoidal roof, planum sphenoidal, 50% lamina papyracea	AEA, PEA, ethmoidal roof, planum sphenoidal, 50% lamina papyracea
Male, 66	10,32	9,58	10.52	13.77	AEA, PEA, ethmoidal roof, planum sphenoidal, 75% lamina papyracea	AEA, PEA, ethmoidal roof, planum sphenoidal, 50% lamina papyracea
Female, 37	10,00	10,49	10.23	9.85	AEA, PEA, ethmoidal roof, planum sphenoidal, 50% lamina papyracea	AEA, PEA, ethmoidal roof, planum sphenoidal, 50% lamina papyracea
Male, 38	11,86	11,65	8.29	11.58	AEA, PEA, ethmoidal roof, planum sphenoidal, 50% lamina papyracea	AEA, PEA, ethmoidal roof, planum sphenoidal, 75% lamina papyracea
Mean (SD)	10.33 (0.98)		11.27 (2.44)			

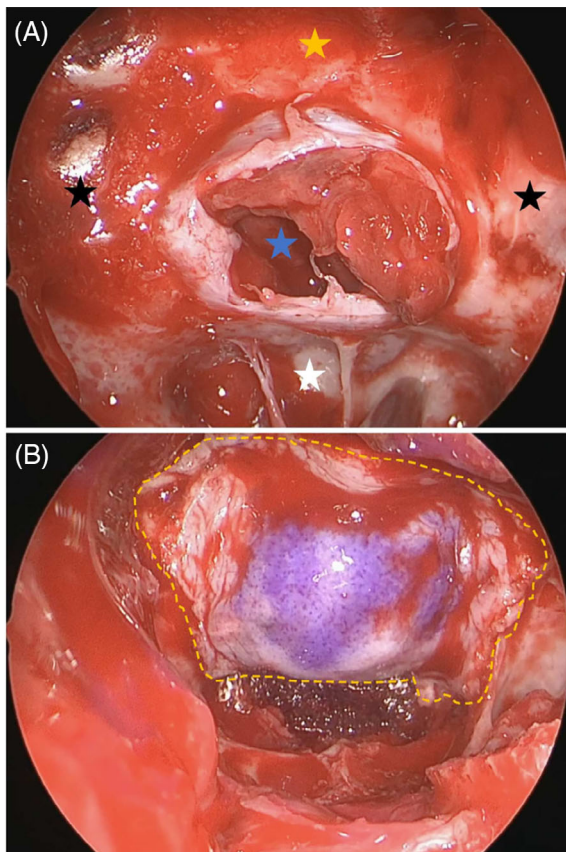
Abbreviations: AEA, anterior ethmoidal artery; CT, computed tomography; EEM, endonasal extended mucoplasty; PEA, posterior ethmoidal artery.



**FIGURE 3** A patient with CRSwNP with an extended ethmoid-sphenoidotomy. A, Right nasal fossa; white star: anterior ethmoidal artery; black star: lamina papyracea; yellow star: frontal recess. B, Left nasal fossa; white star: anterior ethmoidal artery; black star: lamina papyracea; yellow star: frontal recess. C, Yellow dashed line: EEM in the right nasal fossa. D, Yellow dashed line: EEM in the left nasal fossa. EEM, endonasal extended mucoplasty

et al<sup>17</sup> described that the nasal floor mucoperiosteal free grafts could covers large defects of skull base. Our results confirm that measurements for extended mucoplasty obtained from the cadaveric study ensured a 100% coverage area of the ethmoidal roof and at least 75%

coverage of the orbital wall in 73% of the cases, which would ensure posterior control over most of the orbital lateral limit. The uncovered 25% would be at the expense of the anterior region corresponding to the lacrimal bone. Spreading in the posterior sagittal plane, EEM could



**FIGURE 4** A, Transellar approach of a pituitary macroadenoma. A, Black stars: carotid artery; blue star: Transellar approach; yellow star: tuberculum sellae; white star: clivus. B, Yellow dashed line: EEM, endonasal extended mucoplasty

cover the planum sphenoidale in 80% of cases, reaching the tuberculum sellae in 53.3% of the cases.

The EEM has been used in endoscopic sinus surgery, for closure of low-flow CSF fistulas and for repair of large skull base defects after resection of skull base tumors.<sup>17</sup> It has been described in skull base surgery in a large series of sellar closure after pituitary surgery<sup>18</sup> (Figure 4) or septal perforations. The EEM could be used to repair large ethmoid roof defects with high-flow CSF leaks<sup>7</sup> or iatrogenic CSF leaks.<sup>17</sup> EEM can also be used as a complementary procedure to vascularized flaps, such as closure of low-flow CSF leaks after partial necrosis of an extended nasoseptal flap in the clival area.

The extended mucoplasty is technically easy to obtain, it is associated with low local morbidity, unlike other grafts or flaps like nasoseptal flap or extended ones, where the healing of the donor area produces abundant fibrin and scabs in the postoperative period.<sup>19</sup> A better healing of the donor region has been reported in these patients with EEM in the 2 months after the surgery, in contrast with the patients with a nasoseptal flap that can have crusts 4 or 6 months after.<sup>2</sup>

The present findings should be interpreted taking into account the limitations of the study, in particular the reduced number of in vivo specimens from only 4 patients with severe CRSwNP

undergoing extended ethmoid-sphenoidectomy and EEM graft repair. This limited number of patients prevented to perform a correlation analysis of EEM measured on the CT scan and the area of the EEM graft.

## 5 | CONCLUSION

The present descriptive measurements based on a radioanatomical cadaveric study combined with a clinical series study shows that the EEM is a feasible and useful graft to repair defects after performing an extended ethmoid-sphenoidotomy. The EEM grafting was easy to perform and provided an area of coverage for an average of 8.03 cm<sup>2</sup>, which is adequate to be used in the ethmoid-sphenoid roof and orbital wall, and could be even useful in other locations for the repair of defects in skull base surgery. However, the clinical usefulness of this technique should be assessed in a larger number of patients with prolonged follow-up.

## ACKNOWLEDGMENTS

We are grateful to the staff of the Anatomy and Embryology Department of the University of Seville for their contribution to the study, to all patients who voluntarily participated in this project, we are grateful to Marta Pulido, MD, for editing the manuscript and editorial assistance and to Amparo Callejon-Leblic for implementing the radiological measurements methodology.

## CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

## ORCID

Ramón Moreno-Luna  <https://orcid.org/0000-0003-0640-0550>

José Palacios-García  <https://orcid.org/0000-0003-3146-1910>

Alfonso Del Cuvillo Bernal  <https://orcid.org/0000-0003-4332-0920>

Juan M. Maza-Solano  <https://orcid.org/0000-0002-3588-9095>

Serafín Sánchez-Gómez  <https://orcid.org/0000-0002-5897-7821>

Jesús Ambrosiani Fernández  <https://orcid.org/0000-0003-1305-9143>

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**How to cite this article:** González-García J, Moreno-Luna R, Palacios-García J, et al. Radioanatomical study of the extended free nasal floor mucosal graft and its clinical applications. *Laryngoscope Investigative Otolaryngology.* 2020;5:1011-1018. <https://doi.org/10.1002/lio2.503>