Facial Nerve Preservation for Supraorbital Approaches: Anatomical Mapping Based on Consistent Landmarks

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BACKGROUND: The supraorbital keyhole approach (SOKA) provides a safe and advantageous access to the anterior cranial fossa. The implemented skin incision varies depending on surgeon's preferences and requirements. Facial nerve (FN) injury might appear in up to 5.6% of patients. There is a lack of validated tenets for avoiding FN injury.

OBJECTIVE: To define a safety area for FN preservation during a SOKA.

METHODS: Ten dried skulls and 5 injected cadaveric heads (10 sides) were used. A Cartesian frame was created with its horizontal axis at the level of the supraorbital notch and the vertical axis just lateral to the frontozygomatic junction (FZj). FNs were dissected and points along their course were registered and transferred to the Cartesian frame.

RESULTS: Ten microscopic dissections of the FN were performed preserving all branches. A safety area could be defined 8 mm superior and 10 mm inferior to the FZj extending medially to the supraorbital notch and beyond. A 20 mm² area superior and lateral to the FZj provided low probability ($\leq 10\%$) of injuring the FN. Similarly, starting 4 mm inferior to the FZj, a lateral safety area was also found. A probabilistic colored heat map was built to represent the results.

CONCLUSION: We provide a "safety zone" for a SOKA incision in which the probability to encounter the FN is low. Clinical studies following our method may validate our findings and add evidence to the tenets for minimizing morbidity related to the SOKA incision.

KEY WORDS: Facial nerve, Frontozygomatic junction, Mapping, Keyhole, Landmark, Safety Area, Supraorbital notch

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The supraorbital keyhole craniotomy was designed to access the anterior and pituitary fossae through the least invasive route. Following the foundations of minimally invasive keyhole surgery, Perneczky and colleagues^{1–3} used the endoscope to refine such approach to align a small supraorbital craniotomy with many skull base and cerebrovascular lesions. A skin incision along the eyebrow and a 2 × 3 cm craniotomy were initially suggested for an optimal target exposure preserving the integrity of the facial nerve (FN).¹ Promising results were later confirmed

by other authors who extended and popularized the application of this technique.^{4–7}

Variations of the initial supraorbital keyhole approach (SOKA) were suggested to expand the surgical corridor increasing its potential targets.^{8,9} Some of these cases required the skin incision to be extended laterally endangering the temporal branch of the FN. Transient or permanent facial palsy secondary to the SOKA have been inconsistently reported in the literature. However, FN palsy has been estimated in 3.2% for transient and 5.6% for permanent deficits when assessed in clinical reports.^{5,10,11}

Several authors have attempted to define safety areas along the lateral border of the orbit or around the zygoma through anatomic studies.^{12–14} These studies were specifically aimed to facial preservation in pterional¹⁵ or orbitozygomatic approaches.¹⁶ However, there is a lack of anatomical research focused in FN

ABBREVIATIONS: FN, facial nerve; FO, frontooccipitalis; FZj, frontozygomatic junction; OO, orbicularis oculi; SD, standard deviation; SOKA, supraorbital keyhole approach; SON, supraorbital notch

preservation for supraorbital approaches accessed through an eyebrow or supraciliary incision. Essentially, there is poor evidence on where is most safe to place the skin incision during the lateral supraorbital space.¹⁴

We sought to define a safety area for preserving the temporal branch of the FN during supraorbital approaches through an eyebrow incision. We tracked the course of the FN and displayed it as a surface heat map. A novel reference system, based on more consistent landmarks, was developed to assess and represent the results obtained.

METHODS

Ten dried skulls were used to create a standardized and consistent system of references. The supraorbital notch (SON) of both sides was connected through a projected line defining the horizontal axis of coordinates (hereafter “X”). Another line, perpendicular to X, was placed in the lateral aspect of the frontozygomatic junction (FZj), defining the vertical axis (hereafter “Y”) (Figure 1A). The origin of this Cartesian frame, or 0, was set at the intersection of the axis at the FZj. Positive values were assigned to the cranial and medial projections of the axis in both sides. The distances from the lateral edge of the FZj to the SON on the X axis (a) and from the SON to the FZj on the Y axis (b) were measured in mm in these 10 dried skulls and in 5 injected cadaveric heads, for a total of 30 sides (Figure 1B). Averaged distances were calculated to create a universal Cartesian plane where the individual data from every FN were pooled into. Thus, differences in cranial size were averaged and fit into a normalized model. SON morphology was defined, and we specifically noted if it was properly a notch, a foramen, or if it was absent.

Five cadaveric heads were prepared for surgical simulation using our customized embalming formula.¹⁷ FN microdissection was performed bilaterally with a surgical microscope (OPMI Pentero 900, Zeiss, Jena, Germany). A bicoronal incision was made 5 mm anterior to the tragus, inferior to the zygomatic root, and extended upward following the hairline. Skin and subcutaneous layers were dissected from the plane containing the facial muscles (ie, frontooccipitalis [FO], orbicularis oculi [OO], procerus, etc) and transposed (Figure 2). The epidermis and dermis were cut off at the level of the eyebrow to expose the subcutaneous tissue containing the FN and its innervated muscles. As proved by electrophysiological and anatomical studies before, the innervation pattern of peripheral branches of the FN is highly variable.^{18,19} Therefore, a distal to proximal and superficial to deep dissection was preferred to minimize the risk of shattering the minor branches of the nerve. The main branches innervating the FO and OO were identified and followed proximally until the temporofacial division of the main stem of the FN.

Coordinates points (x, y) were assigned to the main branches piercing the FO and OO and to its main branches until their origin in the main stem of the FN (Figure 2). A safety area, where no branches were found next to the superior-lateral aspect of the orbital rim, was outlined, using a minimum of 4 coordinate points. The points representing the course of the FN and the safety area were transferred to an Excel spreadsheet (Excel 2010, Microsoft, Redmond, Washington) and plotted into a Cartesian space defined by the X and Y axis as previously described. These coordinates, which were based on the individual location of the SON and the FZj in every specimen, were normalized and transferred to the unified Cartesian plane with the averaged distances for these points

FIGURE 1. A, A Cartesian frame was defined with an abscissae axis (X) just below the SON and an ordinate axis (Y) just lateral to the FZj. B, Distances from the axis origin to the SON (a) and to the FZj (b) were measured in 10 dried skulls and 5 specimens to establish an averaged Cartesian frame in which to transfer FN coordinates.

(SON and FZj). Normalization of the coordinates was achieved by adding or deducting to x the difference between the individual and averaged coordinates of the SON (x,0). The same operation was done for the ordinate(y) and the difference between the individual and averaged coordinates of the FZj (0, y). The collected data from every FN dissection were pooled in this Cartesian plane. Probability to find a FN branch within an area of 2 × 2 mm was calculated and expressed as a percentage in 10% tiers. A color gradient from green, representing the lowest probability, to black, representing the highest, was assigned to every squared area.

In this manner, the final plot within the normalized Cartesian frame represented the safety areas to place an eyebrow incision for a SOKA.

Institutional Review Board/Ethics Committee Approval

According to the policy of the institution where this research was conducted, ethic committee approval is not mandatory for this kind of studies.

RESULTS

The SON was identifiable in 28 sides of the analyzed specimens, properly as a notch in 19 (63.3%) and as a foramen in 9 (30%). The mean horizontal(a) and vertical(b) distances between the

TABLE. Morphometric Analysis of the 10 Dried Skulls and 5 Injected Cadaveric Heads Regarding the Location of the SON and the FZj

10 skulls and 5 heads			
Morphology	Notch	63.3%	
	Foramen	30.0%	
	Unidentifiable	6.7%	
	Total	100%	
Distance SON-FZj (mm)		Mean	SD
	Horizontal ^a	30.2	4.9
	Vertical ^b	3.4	3.6

^aHorizontal distance (X axis) from the SON to the FZj in millimeters.

^bVertical distance (Y axis) from the SON to the FZj in millimeters.

SON and the FZj were respectively 30.2 mm (standard deviation [SD]: 4.9) and 3.4 mm (SD: 3.6). Results of the morphometric analysis are summarized in the Table.

FN dissection was successfully conducted in all specimens. An intricate patron of innervation was observed in all specimens, with multiple interconnections between the main divisions of the temporal branch of the FN (Figure 2B). Nonetheless, an irregular safety area, where no branches were found, could be defined 8 mm superior and 10 mm inferior to the FZj extending medially along the horizontal axis to the SON and beyond. Beyond these limits the probability of injuring a branch of the FN is higher as the incision is extended laterally and inferiorly. We found that there is an area of 20 mm² at the superior and lateral margin of the FZj that shows null or low probability (10%) of jeopardizing FN. Similarly, a lateral safety area was also found 4 mm inferior to the FZj. Lateral and just inferior (<4 mm) to the FZj an area of approximately 48 mm² accrued a dense innervation. This area corresponded to the branches of the FN that innervate the OO. In addition, in every specimen, branches from the zygomatic division of the FN were identified piercing the inferior half of the OO (Figure 2B). This demonstrated the dual innervation pattern of the OO, whose inferior half is innervated by the temporal and zygomatic branches of the FN and the superior half, is solely innervated by the temporal branch.

The graphic represents the exact coordinates of the registered points along the course of the nerve for every specimen (Figure 3). In addition, a heat map was created illustrating the probability to find the FN in a defined area (Figure 4). This map summarizes the safest and most risky areas in which an incision could be performed (Figure 5).

DISCUSSION

The risk of FN lesion in SOKA through an eyebrow or supraciliary incision has been poorly assessed. Specifically, the best strategy to avoid endangering the temporofacial division of the FN remains unclear. Despite this lack of reported evidence, the rates of transient and permanent FN palsy are not negligible.¹¹ In the present laboratory study, we provided consistent landmarks

FIGURE 4. A, Colored heat map representing the probability to find the FN in a given area in 10% tiers. B, Artistic representation based on the interpretation of results.

to anticipate the location of the FN and to define a safety area in which to perform an eyebrow incision. We defined a probabilistic heat map where both a safety area in the superior-lateral margins of the orbital rim and a hazardous area lateral and inferior to the FZj could be outlined. This strategy to define the boundaries of an incision based on the course of the FN represents a novel method that relies in more consistent landmarks than the reported in the literature, such as the shape of the eyebrow, which is highly variable.

Small incisions and craniotomies together with optimized approaches enhanced by microsurgical techniques are the core principles that support keyhole surgery.¹ Accrued experience has proved that these keyhole approaches are not exempt from complications. A minor complication such as supra-orbital hypoesthesia may occur in 1.3 to 7.6%.^{5,20} of patients. Cerebrospinal fluid leak, whether related or not to frontal sinus opening, may be seen in up to 5.6%.¹⁰ These leaks may be extremely challenging and often require revision surgery implementing various techniques to close the frontal sinus.²¹ Nonetheless, there are many significant advantages that may encourage an experienced surgeon to switch to keyhole surgery: lower rates of cerebrospinal fluid leakage, infections, and postoperative hematomas⁹; better esthetics; and minimal intraoperative blood loss.⁸ Therefore, many authors have suggested modifications on the classical SOKA described by Perneczky and Fries² to extend its indications.⁷⁻⁹ These modifications might require a more lateral incision to better expose Dandy's or MacCarthy's keyholes and take benefit of these strategic landmarks (Figure 5C).

While the medial limit of SOKA is clearly defined by the location of the supraorbital neurovascular bundle¹¹ and the lateral extension of the frontal sinus,²² its lateral limit is not so well established. Recommendations are so ethereal and unspecific as "at the surgeon's discretion"¹¹ or so undefined as 5 to 0 mm lateral to the eyebrow's tip.¹ In general, an ideal landmark would be visible, palpable, and consistent from patient to patient. However, surface facial features are capricious and may experience deep changes over the years. Thus, we consider that a reference system based on tangible, reliable anatomical points provides a better framework to establish surgical recommendations and universalize worldwide and multidisciplinary studies.

In our laboratory investigation, the SOn was unidentifiable in 2 of the 30 sides of the analyzed specimens (6.7%). This does not mean that the SOn was completely absent, as the nerve needs a way out of the skull, but that there might be multiple small foramina and not a single major SOn or foramen. The reported characteristics of SOn morphology are variable: a notch, a single foramen, multiple foramina, and combinations of these features.²³⁻²⁵ Ethnic and climatological features might be involved in the differences between individuals. However, the rates of which these structures can be identified are quite uniform and consistently high, ranging from 98.8 to 100%.^{26,27} An unidentifiable SOn or foramen may limit the applicability of our suggested method, although navigation may reduce that limitation. Nonetheless, the major concern with a SOKA approach is not frontal hypoesthesia, but entering the frontal sinus or injuring the FN.

Our indications rely on consistent, palpable landmarks and provide a safety area adequate to perform a SOKA and some of its lateral variations. Based on the limits of this area, we would recommend an incision superior or within the eyebrow that could be extended laterally 8 mm just over the FZj. Another possible incision to warrant the preservation of the FN could be as the former but extending it inferiorly along the orbital rim and once 4 mm below the FZj turning it laterally up to 14 mm (Figure 5C). This safety area contains the limits of the eyelid incision suggested by Schmidt et al,²⁸ who set the lateral canthus as a surface landmark and identified an area free of nerve branches 25 mm lateral to it. This area was later validated by Aziz et al²⁹ in 40 cases operated through a transpalpebral incision. Although safely

performed by experienced oculoplastic surgeons, transpalpebral approaches may harm the levator palpebrae, resulting in transient or permanent ptosis.²⁹ This fact may prevent the inclusion of this access in the surgical armamentarium for the majority of neurosurgeons.

As proved by electrophysiological and anatomical studies, the innervation pattern of peripheral branches of the FN is highly variable.^{18,19} The branches other than the temporal (frontal, zygomatic, buccal, marginal, and cervical) are frequently and irregularly connected between them and to several mimic muscles.^{18,19,30} Despite this intricate pattern, the frontal and eye area are exclusively innervated by the temporal-facial division of the FN.¹⁸ Our findings support the results of Raslan et al,¹⁸ who

stated that the FO and upper part of OO are solely innervated by the temporal branch of the FN. They also proved that the lower part of OO may share innervation also with the zygomatic and buccal branches.¹⁸ Hence, transecting one of the distal branches innervating the OO would not probably result in a permanent nor complete palsy of this muscle. However, more selective innervation of the FO and the upper part of the OO increase the probability of palsy of these muscles. Thus, we are compelled to handle the tissues with extreme care over these muscles to prevent injuring the FN.

The muscular phase of the approach, needed to expose the bone surface, involves cutting the muscle at some extent. Unavoidably this will result in the violation of the integrity of the muscle fibers and the consequent transient palsy. The severity of this transient paresis and strategies to avoid it cannot be simulated in a cadaveric study. At this level, the neural fibers course intimately bound to the muscle and cannot be dissected. Our study did not include an appropriate mapping of these fibers that run within the muscle. This shortcoming might be only overcome by means of neurophysiological tests.

Limitations

This study harbors some of the usual limitations found in cadaveric studies. However, soft tissue manipulation is not so influenced by cadaveric stiffness as it may occur in cerebral anatomy studies.^{17,31} Even though this study focuses on the location of the incision, there are many other surgical maneuvers that may jeopardize the FN or the muscles innervated by the FN, such as soft tissue manipulation and retraction, the use of electrocautery, reckless dissection, devascularization, etc. The effects of these important factors might not be properly evaluated in a cadaveric simulation. We used the same sample size as in previous research on this topic for mapping the FN^{15,16}; however, 10 paired specimens from 5 cadaveric heads might be a small sample. Even though we were able to define a safety area, a clinical validation study would increase both the power and applicability of the results. This study lays the foundation for such clinical studies. Our purpose was to suggest a novel reference method to track the course of the FN and in this manner, improve our ability to predict its location. Nonetheless, anatomical studies are not the only and absolute way to build a body of knowledge in this issue. Thus, neurophysiological studies could provide helpful information regarding the innervation pattern of facial muscles and anticipating the effects of injuring the nerve in a given location.¹⁸ Starting from a consistent reference framework, as provided in this laboratory investigation, future research could focus on the in vivo electrical stimulation of facial points to define where the incision and approach could be more safely performed.

CONCLUSION

In the present laboratory study, we proved that mapping the course of the FN and defining a safe area to perform a SOKA is possible, and it is based on consistent landmarks, such as the SON

and the FZj. The lateral extension of an eyebrow or supraciliary incision could be contained within an area superior or inferior to the FZj, avoiding a hazardous area just lateral to it, where the FN pierces the OO. Electrophysiological studies could expand the knowledge on this issue often disregarded in these keyhole approaches. The suggested framework could set the basis for further research, allowing to standardize the results of various studies and universalize a consistent methodology.

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENT

This is an interesting study using 10 dry skull specimens and 5 cadaveric heads that assesses the safe zone for preservation of

facial nerve branches when making the skin incision for supraorbital approaches. This is a useful study to give a surgeon guidelines as to where to place the incision so as to minimize chances of injury to the facial nerve branches. There are some limitations of this study to consider when applying this methodology to surgical cases.

As admitted by the authors, the study needs clinical validation, as this limited study in 10 dry skulls and 5 cadaver heads really does not predict what the facial nerve outcome might be. As discussed by the authors, in addition to the location of the incision there are a number of other factors that might affect the postoperative function of the nerve including soft tissue retraction and dissection, devascularization of the nerves, and use of electrocautery which might lead to temporary and in some cases permanent frontalis weakness. Additionally, there may be wide variations in these measurements from one patient to another depending on various factors including age, gender, and ethnicity for example. Because of such potential variations these measurements may not necessarily be broadly applicable to all patients.

The authors developed a cartesian plot system to predict the probability of identifying the distal branches of the facial nerve in anatomical regions around the area of the supraorbital incision. One can predict some potential variability from 1 surgeon to another and even in a single surgeon trying to replicate these measurements as they palpate and identify the anatomical landmarks of the supraorbital notch (SON) and the frontozygomatic junction (FZJ) and then draw the lines for the cartesian plot. Such inter- and intraobserver variability could impact the accuracy and utility of such measurements. The potential challenges of reproducing this technique are confirmed by the authors in that for 2 of 30 sides measured, a supraorbital notch or foramen could not be identified.

Despite these limitations, the study provides guidance as to safe placement of the incision to preserve the facial nerve for during supraorbital approaches. Further validation in clinical cases is needed.

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