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ORIGINAL ARTICLE

Peripheral Nerve

Anatomic Anomalies of the Nerves Treated during Headache Surgery

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Background: Headache surgery is a well-established, viable option for patients with chronic head pain/migraines refractory to conventional treatment modalities. These operations involve any number of seven primary nerves. In the occipital region, the surgical targets are the greater, lesser, and third occipital nerves. In the temporal region, they are the auriculotemporal and zygomaticotemporal nerves. In the forehead, the supraorbital and supratrochlear are targeted. The typical anatomic courses of these nerves are well established and documented in clinical and cadaveric studies. However, variations of this "typical" anatomy are quite common and relatively poorly understood. Headache surgeons should be aware of these common anomalies, as they may alter treatment in several meaningful ways.

Methods: In this article, we describe the experience of five established headache surgeons encompassing over 4000 cases with respect to the most common anomalies of the nerves typically addressed during headache surgery. Descriptions of anomalous nerve courses and suggestions for management are offered.

Results: Anomalies of all seven nerves addressed during headache operations occur with a frequency ranging from 2% to 50%, depending on anomaly type and nerve location. Variations of the temporal and occipital nerves are most common, whereas anomalies of the frontal nerves are relatively less common. Management includes broader dissection and/or transection of accessory injured nerves combined with strategies to reduce neuroma formation such as targeted reinnervation or regenerative peripheral nerve interfaces.

Conclusions: Understanding these myriad nerve anomalies is essential to any headache surgeon. Implications are relevant to preoperative planning, intraoperative dissection, and postoperative management. *(Plast Reconstr Surg Glob Open 2023; 11:e5439; doi: 10.1097/GOX.0000000000005439; Published online 21 November 2023.)*

INTRODUCTION

Chronic headaches are among the most common ailments treated by physicians.[1] According to the most recent Global Burden of Disease Study, migraine headaches constitute the second leading cause of years lived with disabilities worldwide.[2] Not surprisingly, chronic headaches represent an enormous burden to medical systems both in the United States and abroad.[3–7] Over the past 23 years, surgical treatment for chronic headaches has been established as a safe and effective method of treating patients for whom conventional treatment modalities have proven ineffective.[8–12] Moreover, surgical treatment of headaches results in clear, symptomatic improvement, and a reduced dependence on migraine medications.[13] These benefits have culminated in a formal position statement by the American Society of Plastic Surgeons supporting their use in the clinical setting.[14,15]

There are seven distinct and identifiable nerves within the head and neck region (outside the nasal cavity) that constitutes the surgical targets for most headache

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operations. These nerves are the greater, lesser, and third occipital nerves in the posterior scalp,[16–19] the auriculotemporal and zygomaticotemporal nerves in the temporal region,[20–22] and the supraorbital and supratrochlear nerves in the forehead.[23,24] The typical anatomic courses of these nerves have been well described. However, there is considerable variability in the anatomic position of these nerves which can pose surgical challenges. Therefore, a thorough understanding of possible anomalous anatomy would allow the headache surgeon to treat patients intraoperatively more precisely. In addition, although uncommon, some patients have persistent discomfort following adequate surgical treatment of the nerves in question,[25,26] and an awareness of these anatomic variations might help to explain persistent symptoms and to guide future treatment.

In this article, we describe several common nerve anomalies encountered by headache surgeons and categorize them by anatomic region and nerve. These descriptions are based on more than 4000 combined surgical procedures performed by the authors. A consensus of the authors established the approximate frequency of each of the anomalies described.

OCCIPITAL REGION

Greater Occipital Nerve

The greater occipital nerve (GON) is one of the most common nerves addressed during surgery for chronic headaches. It arises from the medial division of the dorsal ramus of the C_2 spinal nerve roots and takes a circuitous route through the soft tissues of the head and neck to innervate the posterior scalp.[27] There are six potential compression points that have been carefully elucidated for the GON, and all must be evaluated and/or addressed for complete decompression.[28] The GON is typically described as having one main branch as it passes through the nuchal musculature, heading cephalically through the tendinous insertions of these muscles at the posterior cranial base or nuchal line (Fig. 1A and B). Not uncommonly, however, this nerve is found branching caudal to the nuchal line. On occasion, there are two large branches of the nerve, split by a section of semispinalis muscle (Fig. 2A). In this case, muscle must often be resected both medial to the medial branch of the GON and lateral to it (ie, the muscle separating the two main branches). The end-point in this dissection should be complete visualization of the confluence of the two branches proximally and complete decompression of both branches distally (Fig. 2B). In some cases, once the intervening slips of the semispinalis have been removed, the two branches of the GON recombine (Fig. 2C). In both clinical scenarios, it is likely that the intervening segment of the semispinalis serves as a compression point that must also be released for complete decompression. This anomaly occurs in approximately 25% of cases. Yet in other cases, the GON branches are split by fascial slips of the trapezius muscle (Fig. 3A). In this situation, the accessory slips of fascia can also be “kink points” of the GON during neck motion and should be released to allow for transposition of the nerve branches to a more relaxed lie (Fig. 3B). This anomaly occurs in approximately 10% of cases.

Takeaways

Question: Conventional wisdom holds that nerves treated during headache operations have consistent anatomic courses, but anomalies have been encountered by many surgeons.

Findings: The combined experience of five seasoned headache surgeons encompassing over 4000 cases is described. Anatomic variations occur commonly with a frequency ranging between 2% and 50% and in multiple locations within the head and neck.

Meaning: Knowledge of these variations in anatomy is critical for any headache surgeon, with practical implications for preoperative, intraoperative, and postoperative patient management.

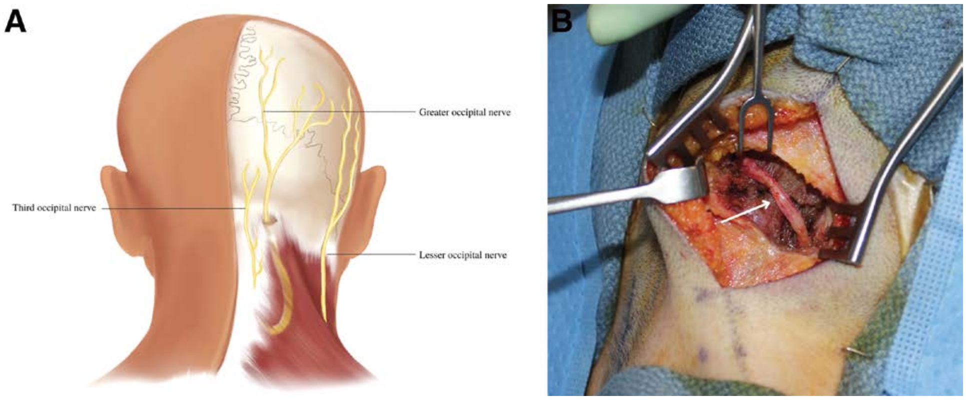

Fig. 1. “Typical” anatomic course of the GON. A, This illustration demonstrates the “typical” anatomy of the occipital nerves. The GON is often seen as a single large nerve trunk that branches only once cephalic to the nuchal line. The LON and TON are typically thought of as distinct nerves with no connections to the GON and have similar branching patterns. B, This picture shows the “typical” anatomy of the GON in situ with a branching pattern corresponding to part A.

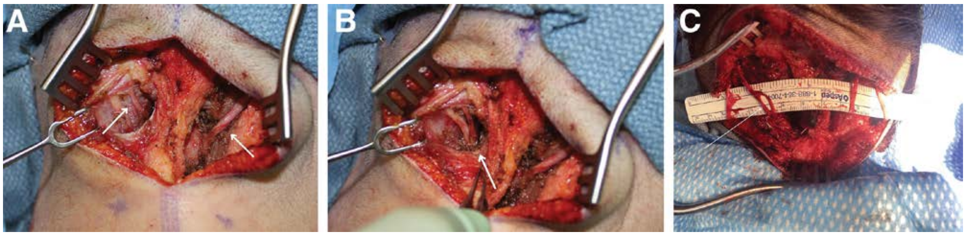

Fig. 2. Proximal anomalous branching pattern of the GON. A, The typical anatomy of the greater occipital nerve seen on the patient's right side with a single, large nerve visible (right-sided white arrow). However, on the contralateral side, a bifid greater occipital nerve is seen with two distinct branches split by slips of the semispinalis muscle (left-sided white arrow). B, Confluence of the two branches of the left GON proximally following removal of the intervening piece of semispinalis muscle (white arrow). C, Confluence of the two branches of the left GON proximally and distally following removal of the intervening piece of semispinalis muscle (white arrow).

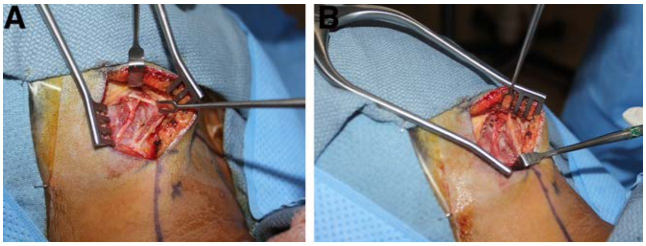

Fig. 3. Distal anomalous branching pattern of the GON. A, Branches of the GON split by a fascial slip of the trapezius muscle. B, A more relaxed lie of the right-sided GON branches following release of the tendinous slip of the trapezius muscle from A.

Another common anatomic anomaly of the GON occurs when there are multiple branch points caudal to the nuchal line (Fig. 4). This anomaly occurs in approximately 40% of cases. In this case, the branches are often small and consist of tiny fascicles that, when dissected into the soft-tissue plane, seem neuromatous when compared with the main GON trunk. This situation presents the surgeon with a challenging clinical decision: to leave the potentially permanently damaged fascicles in place or to transect them. If the latter option is chosen, there are several maneuvers that can be used to manage the transected nerve end. When the fascicles are small and clearly damaged, they can be neurolysed back to healthy nerve or to the main occipital nerve trunk. If neurolysis results in a long branch, regenerative peripheral nerve interface (RPNI) implantation can be performed using the excised semispinalis muscle.[29] Alternatively, an epineurial window can be made within the main GON trunk and an end-to-side repair performed more distally. Another option is to transect the small fascicle at its branch point at the main trunk and to suture the resulting epineurial defect with an 8-0 or 9-0 nylon suture to prevent collateral sprouting. Furthermore, reset-neurectomy, or transection of the sensory nerve proximal to the area of injury with coaptation to the distal nerve end, is another method to alleviate symptoms in a grossly damaged nerve. Resection of the small segment of healthy nerve proximal to the site of injury eliminates afferent nerve signals and allows for regeneration of the native nerve, which serves as a graft.[30]

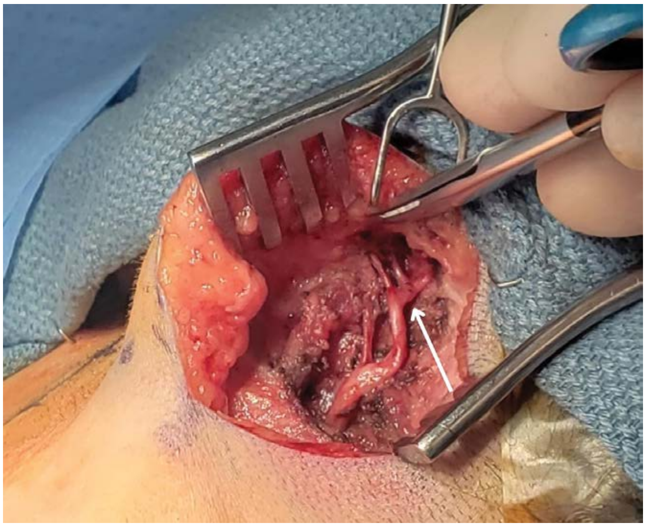

Fig. 4. GON with multiple branch points caudal to the nuchal line (white arrow).

Lesser Occipital Nerve

The lesser occipital nerve (LON) derives from the ventral rami of the C_2 and C_3 spinal nerves and passes from Erb's point cephalically through several compression points deep to and behind the sternocleidomastoid muscle.[19] Like the GON, the LON is often depicted as having one main branch until it passes cephalic to the nuchal line (Fig. 1A). However, as with the GON, sometimes the LON branches much more caudally (Fig. 5A). In this case, the connective tissue separating the branches must be released so that the individual branches achieve a more relaxed lie within the surrounding nuchal soft tissues (Fig. 5B).

The surgeon must also keep in mind that these other branches (or in some cases the single LON) can be found as far medially and posteriorly as the lateral border of the trapezius which should constitute the posterior extent of dissection in these cases (Fig. 6A). Clinically, these variations may present as only partial relief of neck/migraine pain after preoperative nerve block due to the presence of posteromedial branches that are often the reason for this partial

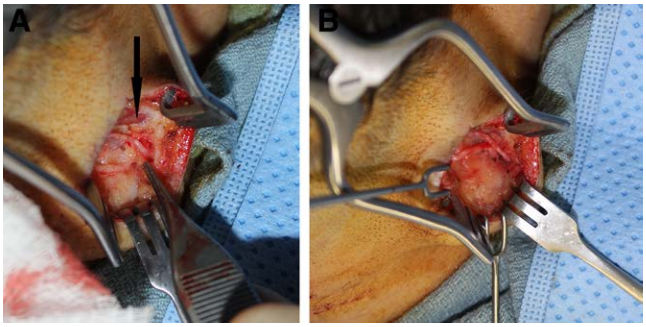

Fig. 5. Anomalous proximal branching pattern of the LON. A, LON seen through a lateral neck incision with visualization looking caudally. The black arrow highlights the posterior border of the sternocleidomastoid muscle, and the tip of the forceps is seen tugging on the intervening fascial band between two proximal branches. B, LON from A with surrounding connective tissue fully released to allow for decompression of individual branches which have a more relaxed lie and reconstitution of the vasa nervorum.

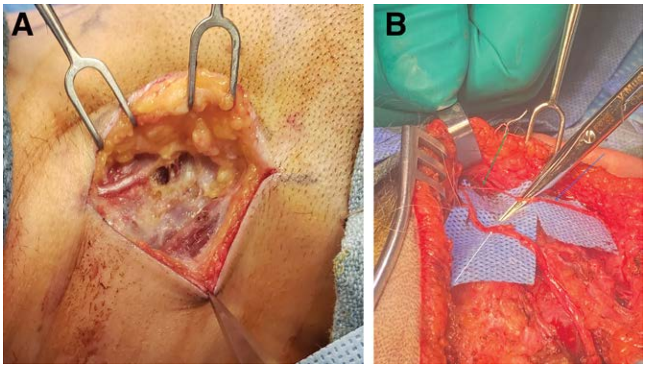

Fig. 6. Positional and distal anomalies of the LON. A, LON in a "less typical" postero-medial location at the lateral edge of the trapezius muscle. B, LON (blue arrow) with distal, crossing connections (green arrow) to the GON (white arrow).

response. This clinical scenario can be determined by an additional nerve block at the lateral trapezial border which, if successful, should guide dissection to the lateral trapezius during the ensuing operation. Anatomically, the authors also found that when the LON is unexpectedly small at the posterior sternocleidomastoid muscle border (especially in the setting of a large or obese patient), there is often another branch more posteromedially and a careful dissection in this direction is warranted. The multibranch anomaly occurs in approximately 30% of cases. Rarely, the LON can have connections with the GON distally (Fig. 6B). If the LON takes a very posteromedial course, dissection should proceed cephalic to the nuchal line for complete decompression to potentially uncover those crossing branches, or the LON should be resected and managed as noted previously. This unusual anomaly occurs in only approximately 10% of cases.

Third Occipital Nerve

The third occipital nerve (TON) emanates from the superficial, medial branch of the dorsal ramus of the C_3 spinal nerve and passes through the semispinalis and trapezius much like the GON. It is typically much smaller in caliber when compared with the GON and is found more superficially and caudally. This nerve is commonly depicted as passing in a paramedian vector cephalically and usually runs medial to the GON (Fig. 1A). One common anomaly, however, is passage of the TON lateral to the GON (Fig. 7). Slightly less common is a variation with a direct connection between the TON and GON (Fig. 8). This scenario presents yet another challenging decision point. Oftentimes, the TON appears neuromatous and can be safely transected. However, if connected to the GON, neurolysis and preservation of the nerve is also an option. Alternatively, the nerve can be transected at its connection point with the GON and the resultant epineurial window sutured closed or the transected TON stump placed within an RPNI as described earlier. At

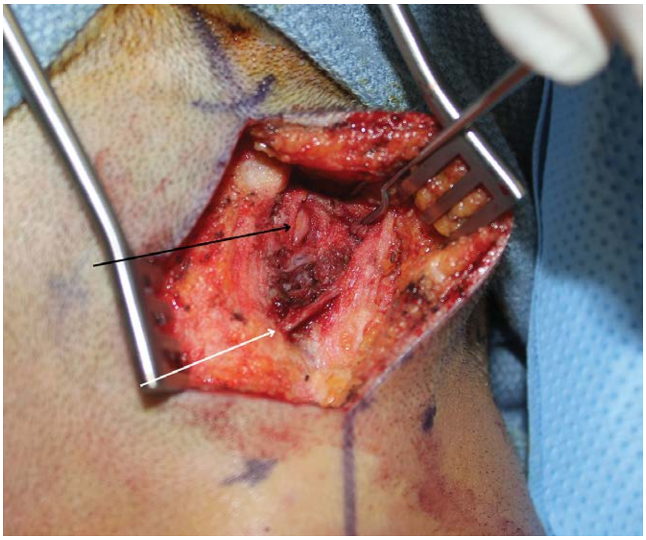

Fig. 7. TON (white arrow) located lateral to the GON (black arrow).

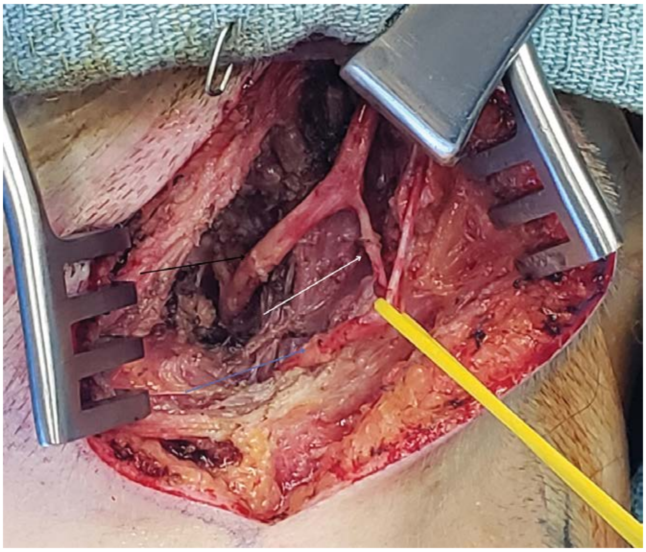

Fig. 8. Communicating branch (white arrow) between the TON (black arrow) and GON (blue arrow).

this time, it is unclear which technique will yield better outcomes.[30] The potential advantages of RPNI include the abundance of muscle in the nuchal and temporal regions, and the fact that formal microsurgical experience is not a necessity for performing this technique. The potential disadvantages include the relative lack of musculature in the frontal regions and the possible nonviability of the larger muscle graft required for large nerves such as the GON. Alternatively, the advantage of targeted reinnervation includes a direct nerve to nerve coaptation, whereas the possible disadvantages are the need for a slightly greater amount of dissection in the operative field and the need for formal microsurgical experience in executing this technique. However, both techniques have been used with clinical success in the prevention of neuropathic pain in similar situations.[31,32] The consensus of the authors is that both techniques are used with approximately equal frequency and success at this time.

TEMPORAL REGION

Auriculotemporal Nerve

The auriculotemporal nerve (ATN) is a branch of the mandibular (V_3) division of the trigeminal nerve.[27] The compression topography of this nerve has been well delineated and consists of two fascial bands near the helical root of the auricle and a third band at the intersection of the nerve with the superficial temporal artery.[33] Several anatomic anomalies of the course of this nerve exist. As with the other nerves mentioned thus far, additional branches are commonly found in approximately 50% of patients. Branches directed anteriorly have been described,[20] and occasionally, posterior branches are identified during surgery (Fig. 9). When the location of the patient's temporoparietal pain is somewhat posterior and a clinically significant, yet partial response to preoperative, diagnostic blocks at the helical root are noted, a posterior branch may be the cause. Careful intraoperative dissection posterior to the helical root is suggested and often reveals a small nerve branch that must be appropriately managed.

With respect to the superficial temporal vessels, the ATN is typically found superficial to these vessels or within the same plane and is often entrapped within thick connective tissue, leading to the "pounding" or "pulsating" quality of the headache noted in most of these patients. However, when a meticulous search for the ATN is performed in these typical locations and the nerve cannot be identified, it may be located deep to the vessel in question (Fig. 10A, B). The authors therefore recommend routine ligation or cautery of the superficial temporal vessels for all cases involving the ATN.

Fig. 9. Bifurcating, right-sided ATN with a clearly visible posterior branch.

Zygomaticotemporal Nerve

The zygomaticotemporal nerve (ZTN) is a branch of the maxillary (V_2) division of the trigeminal nerve.[27] It passes deep to the temporalis muscle and can have both a short or long intramuscular course or even a completely extramuscular course.[21] The primary type of anomaly seen with this particular nerve is the presence of additional branches, seen in approximately 25% of patients. In the authors' experience, most cases involving the ZTN have a single nerve branch, but in some cases, two branches (Fig. 11) or even three branches (Fig. 12) can be found.

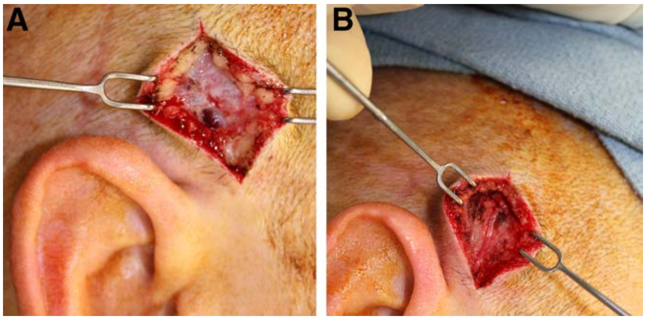

Fig. 10. ATN located deep to a superficial temporal vessel before (A) and after (B) decompression with vessel removal.

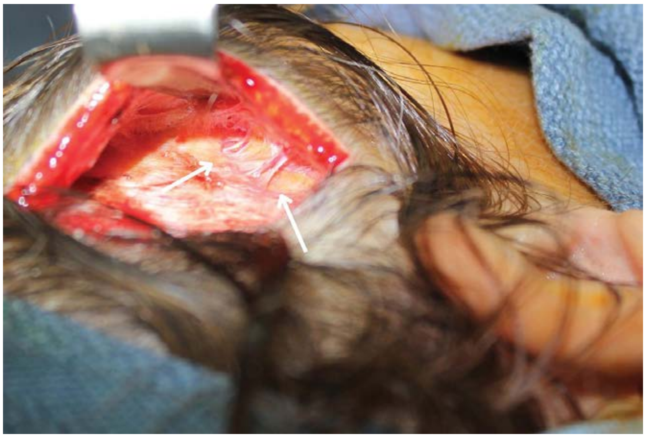

Fig. 11. ZTN with two distinct branches.

Fig. 12. ZTN with three distinct branches.

Our recommendation, therefore, is to perform dissection from the lateral/posterior of the orbital rim to the zygomatic arch caudally and as guided by the area of greatest discomfort preoperatively cephalically and posteriorly, even if a ZTN nerve is identified early in this dissection zone. In this way, no additional ZTN branches will be missed inadvertently.

FRONTAL REGION

Supraorbital Nerve

The supraorbital nerve (SON) is a branch of the ophthalmic (V_1) division of the trigeminal nerve. It passes from the orbital roof either through a supraorbital notch or foramen to innervate the majority of the forehead often up to and sometimes posterior to the anterior hairline (deep branch).[34] As with the other nerves described thus far, the SON can have branches that take unusual routes through bony and soft tissues of the forehead. In a prospective, intraoperative study of patients undergoing surgical decompression of frontal trigger sites, 49% of the decompressed SONs traversed a single supraorbital notch, whereas 41% traveled through a supraorbital foramen.[35] In some cases, typical dissection can reveal what may be a nearby supratrochlear nerve (STN) that passes deep to the orbital rim. (**See figure, Supplemental Digital Content 1**, which shows the SON passing through an orbital rim with another nerve branch seen medially, seemingly consistent with the STN, **http://links.lww.com/PRSGO/C895**.) Careful ostectomy may need to be combined with some degree of intraconal dissection posteriorly to convert this foramen into a notch and completely release the SON from its tight periosteal sleeve. In doing so, the surgeon often finds that the nearby branch originally thought to be the STN is a branch of the SON which is stretched around the orbital rim with every glabellar muscle contraction. Only upon full release of the periosteal sleeve can this branch take a more favorable route through the local soft tissues with additional dissection medially allowing for identification of the STN proper which should also be addressed. [**See figure, Supplemental Digital Content 2**, which shows supraorbital foramen now converted to a notch demonstrating the aforementioned branch (white arrow) as a component of the SON, **http://links.lww.com/PRSGO/C896**.] Other described anomalies in the course of the supraorbital nerve involve a deeper intraconal dissection revealing SON bifurcation into deep and superficial branches before exiting through two notches [**see figure, Supplemental Digital Content 3**, which shows intraconal SON bifurcation (white arrows) with one branch exiting though a notch and one branch exiting through a foramen, **http://links.lww.com/PRSGO/C897**] or two separate foraminae [**see figure, Supplemental Digital Content 4**, which shows SON bifurcation into deep and superficial branches (white arrows) before exiting two foraminae, **http://links.lww.com/PRSGO/C898**] or the presence of both a notch and foramen whereby the superficial branch of the nerve traverses the notch, and the deep branch traverses the foramen. These anomalies are found in approximately 15% of patients, collectively. Very rarely (approximately 2% of patients), the nerve travels through neither a notch nor a foramen, rather traveling inferiorly around the orbital rim.[35] Finally, on occasion, the supraorbital foramen is found several centimeters cephalic to the orbital rim (**see figure, Supplemental Digital Content 5**, which shows supraorbital foramen located several centimeters cephalic to the orbital rim, **http://links.lww.com/PRSGO/C899**], and this variation should be kept in mind when dissection at the rim does not yield any identifiable SON nerve branches. A long ostectomy is required to allow the nerve to fully transpose out of the bone and to perform a complete decompression. (**See figure, Supplemental Digital Content 6**, which shows the SON fully transposed following a long ostectomy, **http://links.lww.com/PRSGO/C900**.) This variation is seen in approximately 10% of cases.

Supratrochlear Nerve

The STN is also a branch of the ophthalmic (V_1) division of the trigeminal nerve. It is typically located quite medially in the supraorbital region when visualized through a transpalpebral approach and is often depicted as a single nerve bundle emerging from the orbital rim. The primary anatomic anomaly for this nerve lies in multiple branches which must be fully released. [**See figure, Supplemental Digital Content 7**, which shows an STN with multiple branches (white arrows), **http://links.lww.com/PRSGO/C901**.] As with the SON, the STN branches can also pass through bony foramina and must be managed accordingly. [**See figure, Supplemental Digital Content 8**, which shows the STN (white arrow) passing through a bony foramen before release, **http://links.lww.com/PRSGO/C902**.] [**See figure, Supplemental Digital Content 9** which shows the STN (white arrow) passing through a bony foramen after release, **http://links.lww.com/PRSGO/C903**.] The multifidous STN is seen in approximately 30% of patients, and a foraminal passage of the STN only occurs in 3% of cases.

CONCLUSIONS

This article describes the most common anomalies involving the primary nerves treated during headache surgery in various areas of the head and neck. It is our belief that an understanding of these possible variations in nerve course can aid the headache surgeon in assessing patients preoperatively and in managing them both intraoperatively and postoperatively. As our understanding and experience with surgical techniques for chronic headaches develop, additional anatomic variations will likely be defined and will further improve our clinical outcomes.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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